Coaxial Transmitting Chokes

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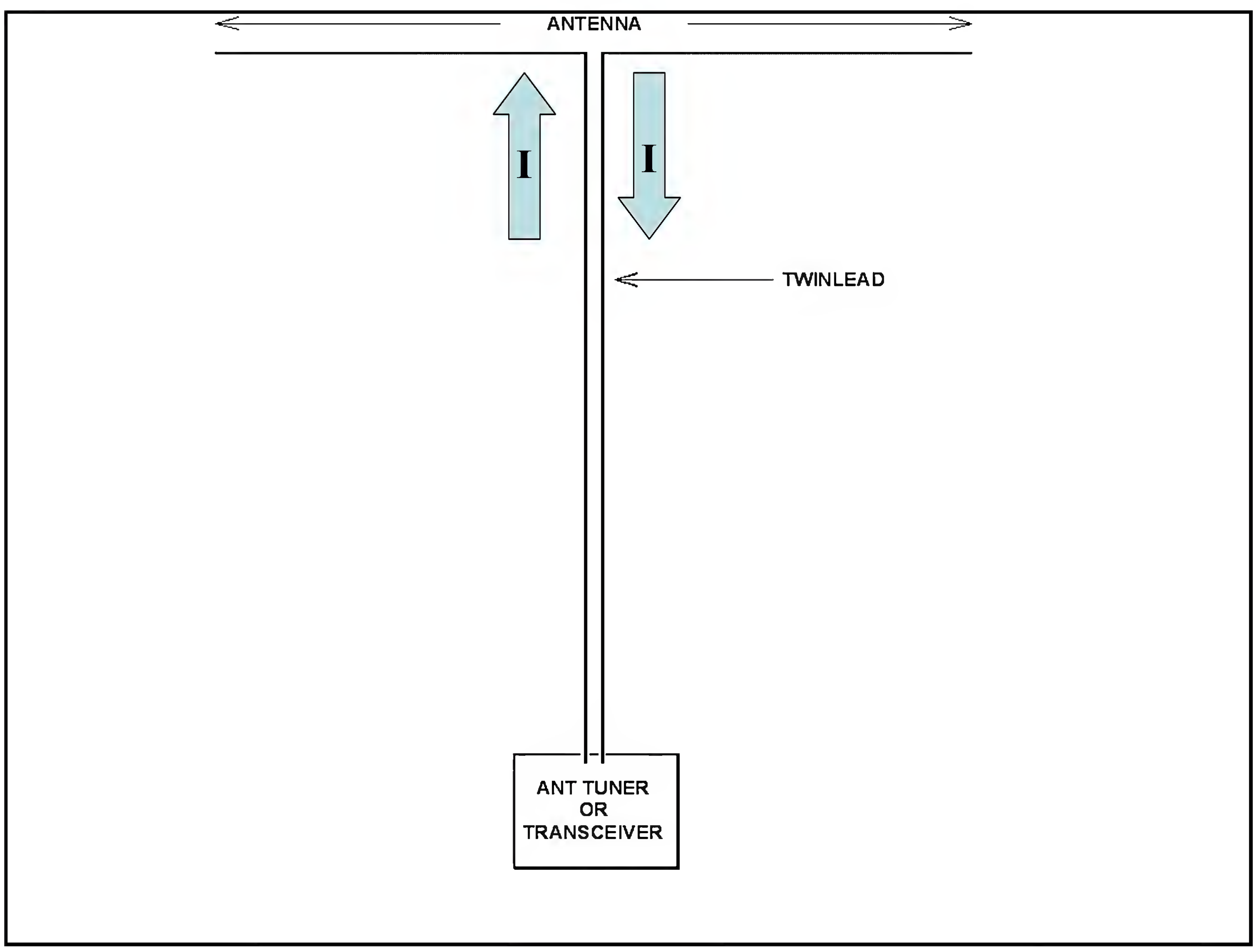
Understanding Common Mode and Differential Mode Currents on Transmission Lines

Differential Mode Current

- Transmission line carrying power from transmitter to antenna, or from antenna to receiver
- Signal is voltage between the two conductors
- Current flows out on one conductor and returns on the other

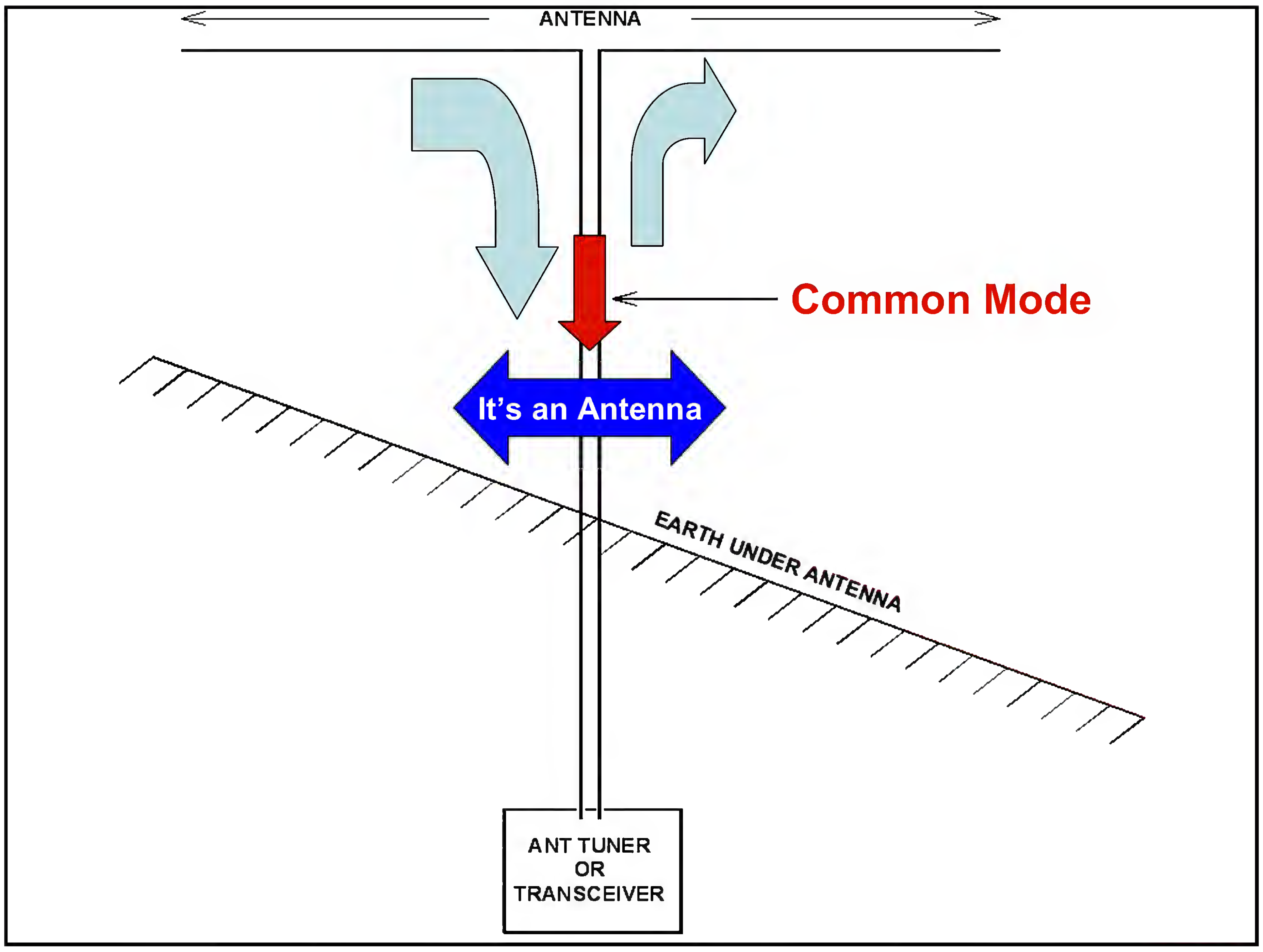


Differential Mode Current

- Transmission line carrying power from transmitter to antenna, or from antenna to receiver
- Signal is voltage between the two conductors
- Current flows out on one conductor and returns on the other
- Fields exist between the two conductors
- No radiation from ideal line
  - Field of outgoing conductor cancels field of return conductor

Common Mode Current

- Equal and flowing in the same direction on all conductors of balanced lines
- Current flows lengthwise on the line
  - No cancellation of one current by another, because they're in polarity
- Line acts as long wire antenna
  - It radiates and it receives



Ham Antennas and Balance

- **Most ham antennas are <u>unbalanced</u> by their <u>surroundings</u>, even when fed by a balanced source and line**

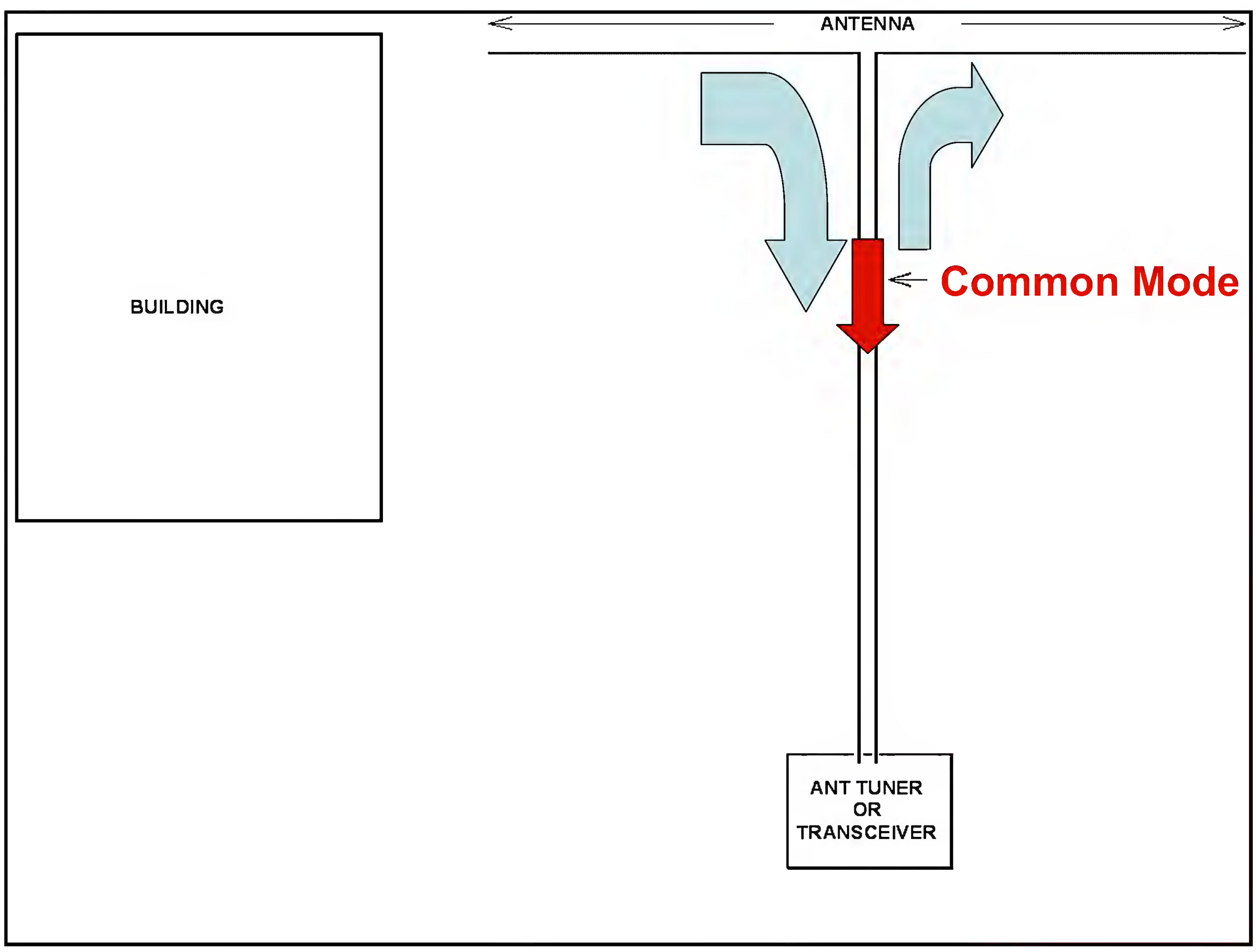
What Makes a Balanced Circuit?

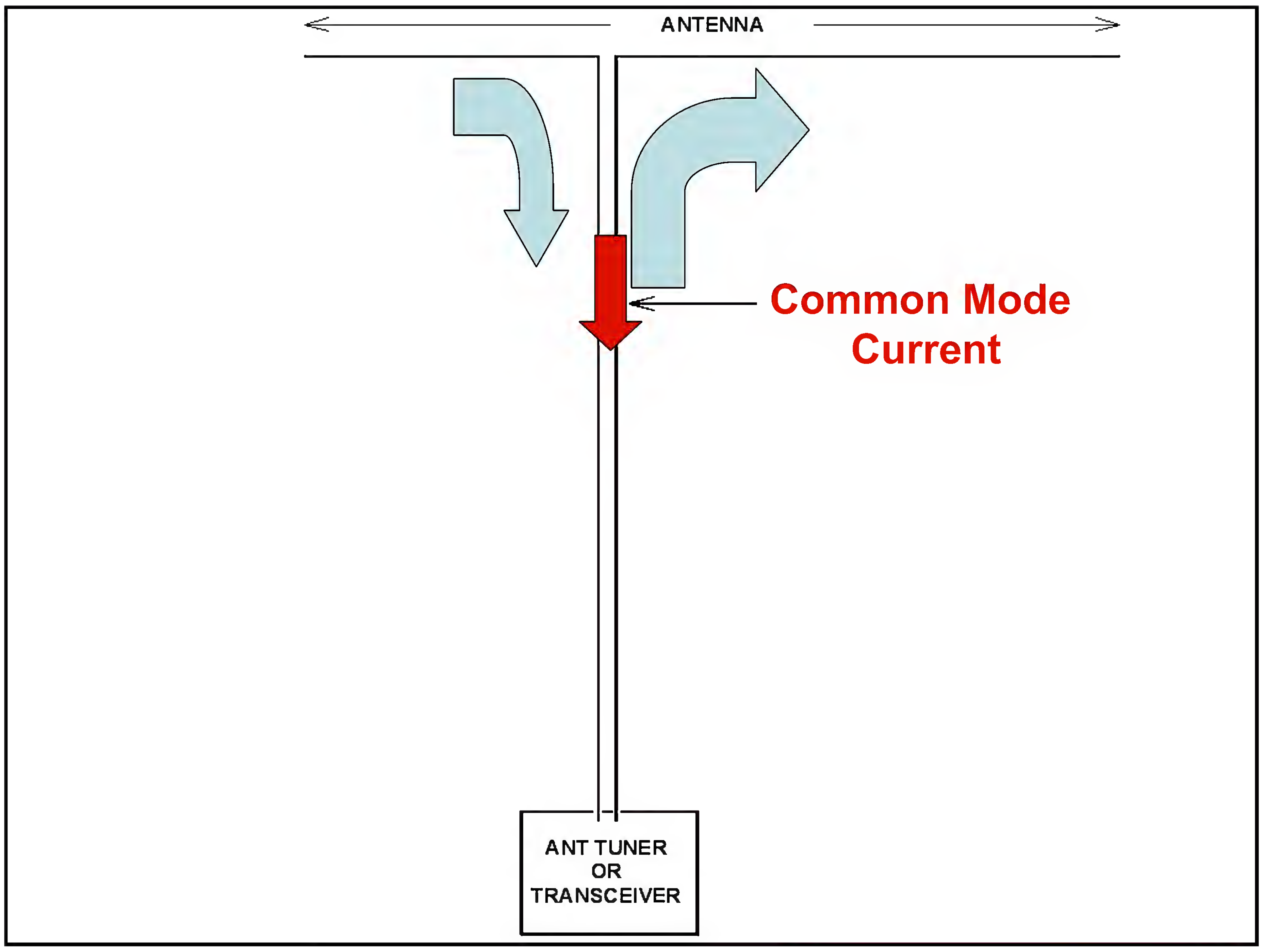
What Makes a Balanced Circuit?

- **The impedances of each conductor to the reference plane are equal**
- **Balance is <u>not</u> defined by voltage or current**

Ham Antennas and Balance

- Most ham antennas are <u>unbalanced</u> by their <u>surroundings</u>, even when fed by a balanced source and line
  - Unequal capacitances to nearby conductors
  - Unequal inductive coupling to nearby conductors
  - Trees, buildings, towers, terrain
  - Coax is not a part of this imbalance





Unbalanced Antennas and Lines

- If the antenna is unbalanced
  - Unequal voltage and current to earth
  - Unequal currents on the feedline
  - The difference is common mode current, and it radiates from the line
- Coax did not cause the imbalance in these antennas!

The Fields around Coax and Twinlead are Very Different

Coax is Special

- All the differential power (and field) is confined <u>inside</u> the coax
- All the common mode power (and field) is <u>outside</u> the coax
- <u>A ferrite core surrounding coax sees only the common mode power (and field)</u>

Coax is Special

- **Skin effect splits the shield into two conductors**
  - **Inner skin carries differential mode current (the transmitter power)**
  - **Outer skin carries common mode current (the current due to imbalance)**

Twinlead Has Leakage Flux from Differential Current

- **This leakage flux is not confined to the region between the conductors, but instead spills to the area immediately surrounding the conductors**
- **Leakage flux causes very little radiation, but it will cause heating in a lossy medium!**

How Much Leakage Flux?

- Depends on mutual coupling between conductors
  - Depends on conductor-to-conductor spacing
  - How close together can conductors be?
- Coupling coefficient of 60-70% typical
  - 30-40% leakage flux in <u>best</u> balanced cables

We'll talk more about all this later on

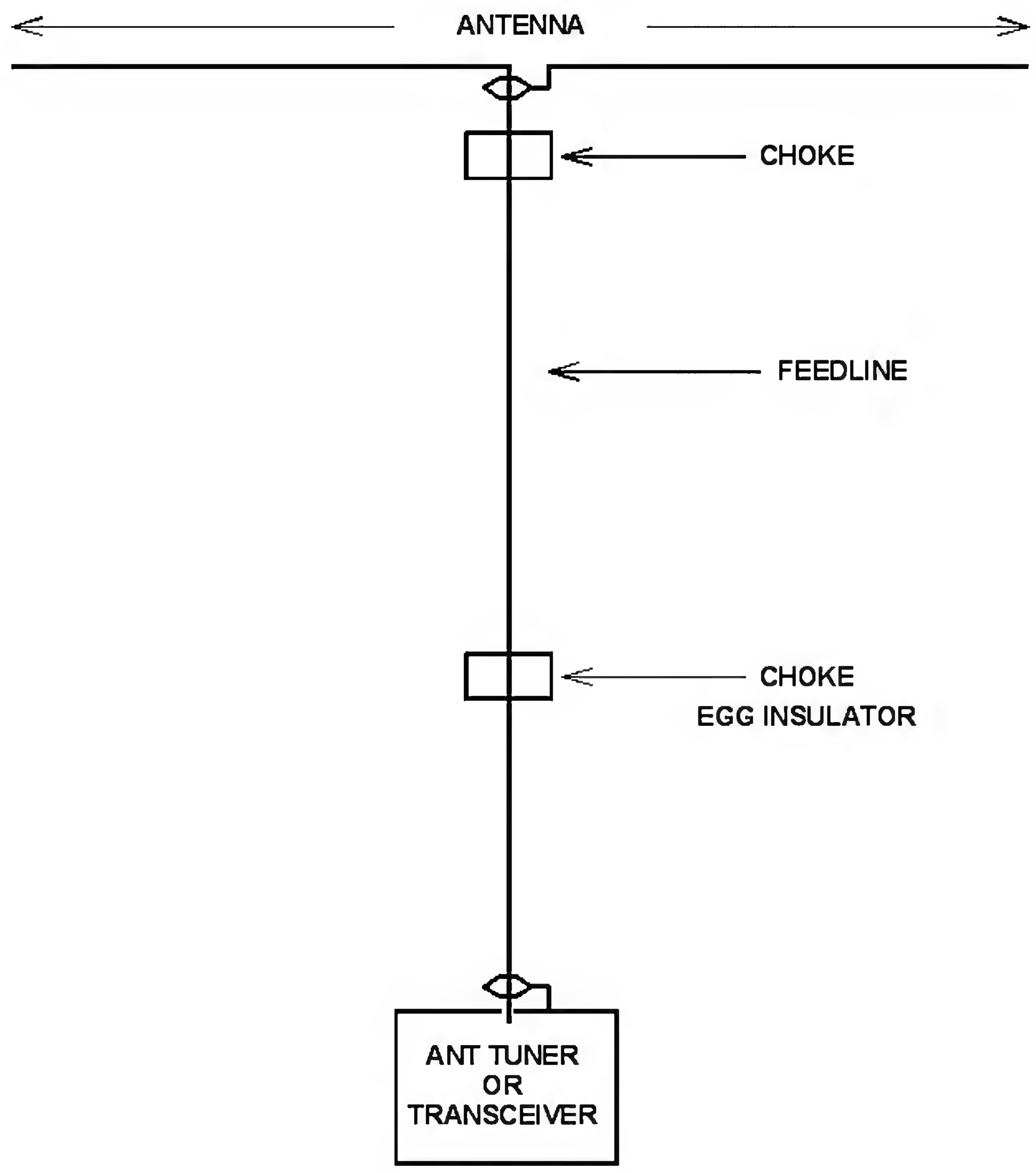
Now We Can Talk About Common Mode Chokes!

What's a Common Mode Choke?

- A circuit element that reduces common mode current by adding a high impedance in series with the common mode circuit
  - Reduces <u>radiation</u> from the coax
  - Reduces <u>reception</u> by the coax

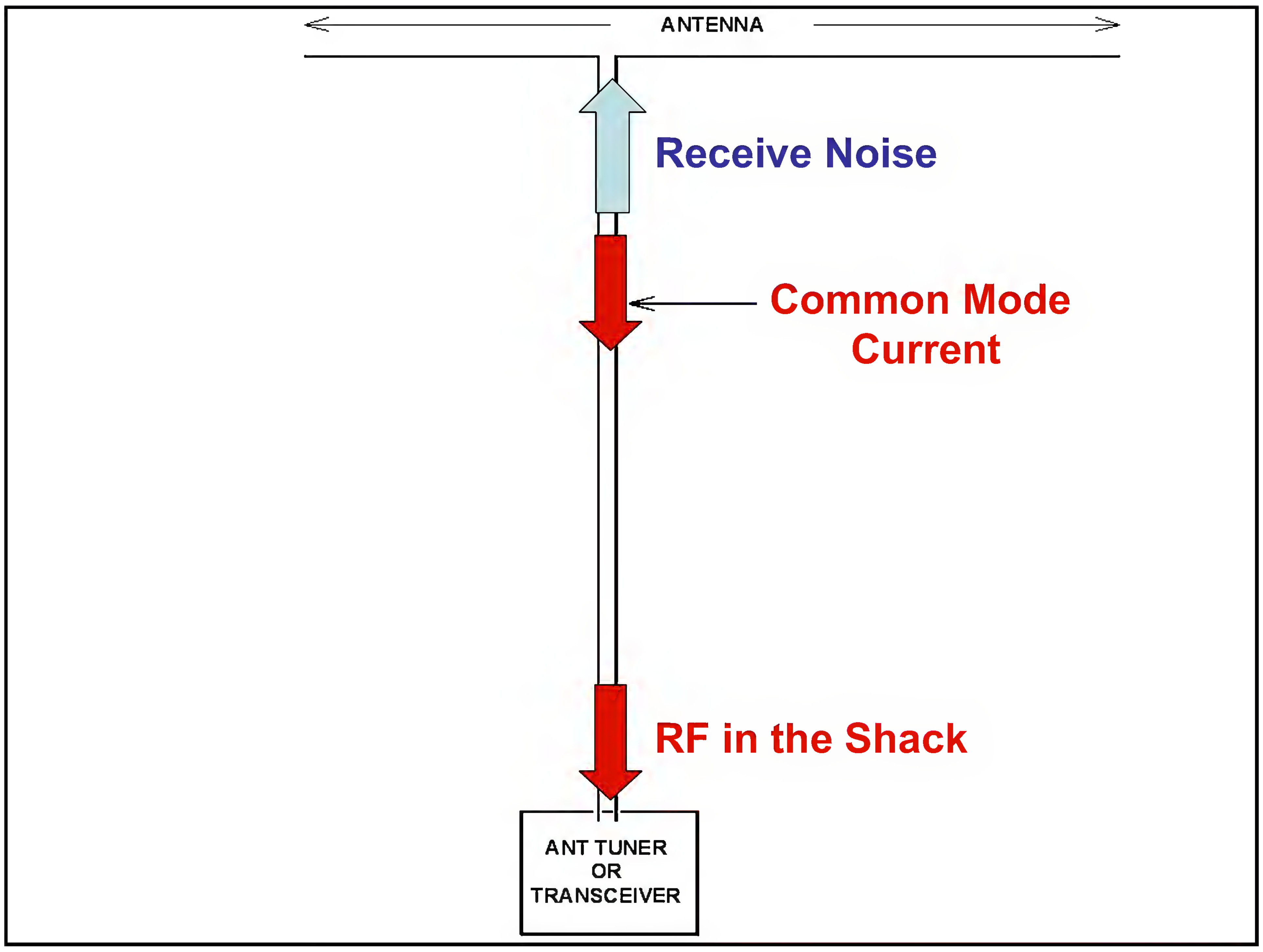
Some Common Mode Chokes

- A coil of coax at the antenna
- A stack of ferrite beads around coax (Walt Maxwell, W2DU)
- Multiple turns of transmission line through a toroid or stack of toroids
- Most 1:1 "baluns" are common mode chokes



Why Transmitting Chokes?

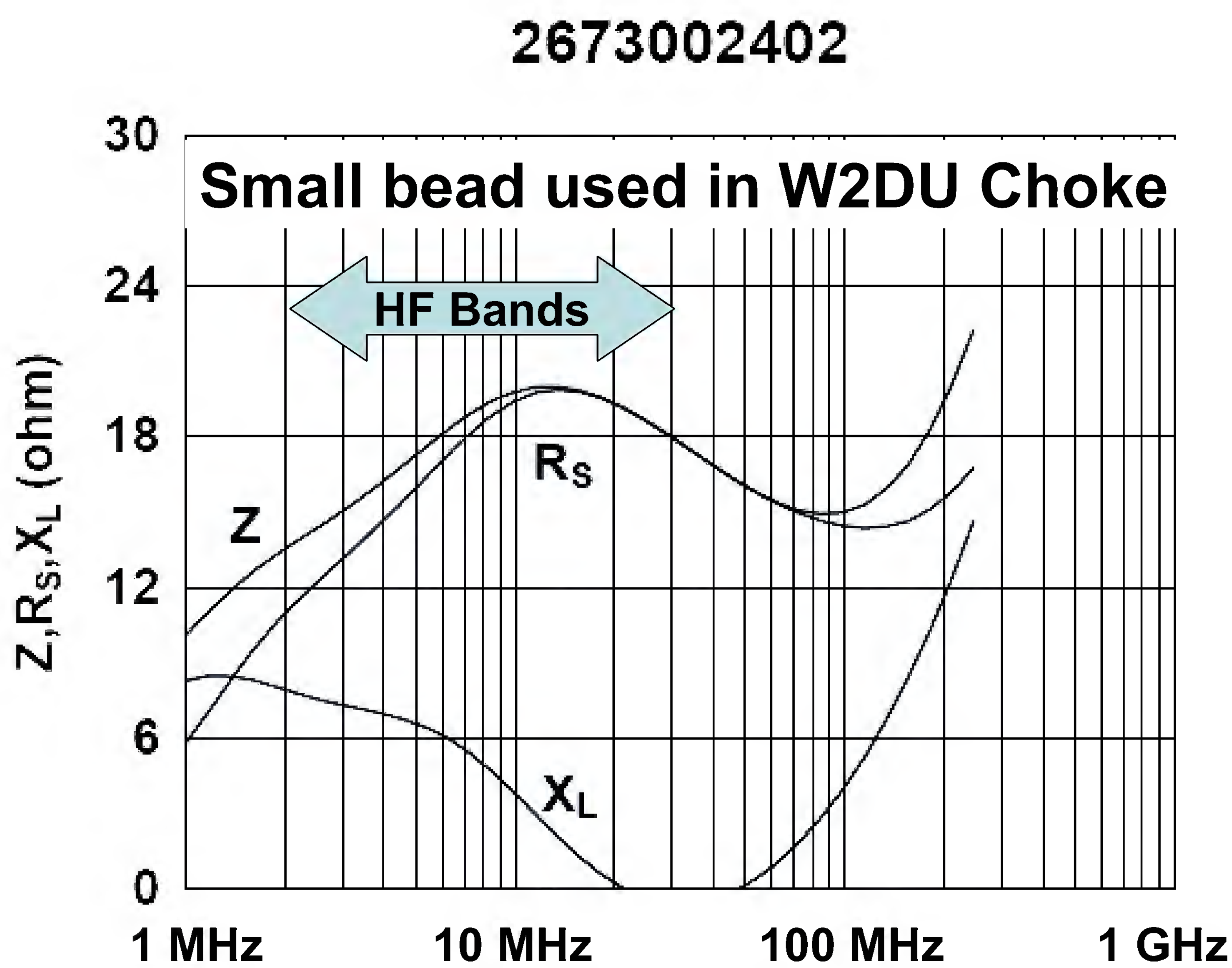
- Isolate antenna from its feedline
- Reduce receive noise
- Keep RF out of the shack
- Minimize antenna interaction
  - SO2R, Multi-multi



Design of Transmitting Chokes

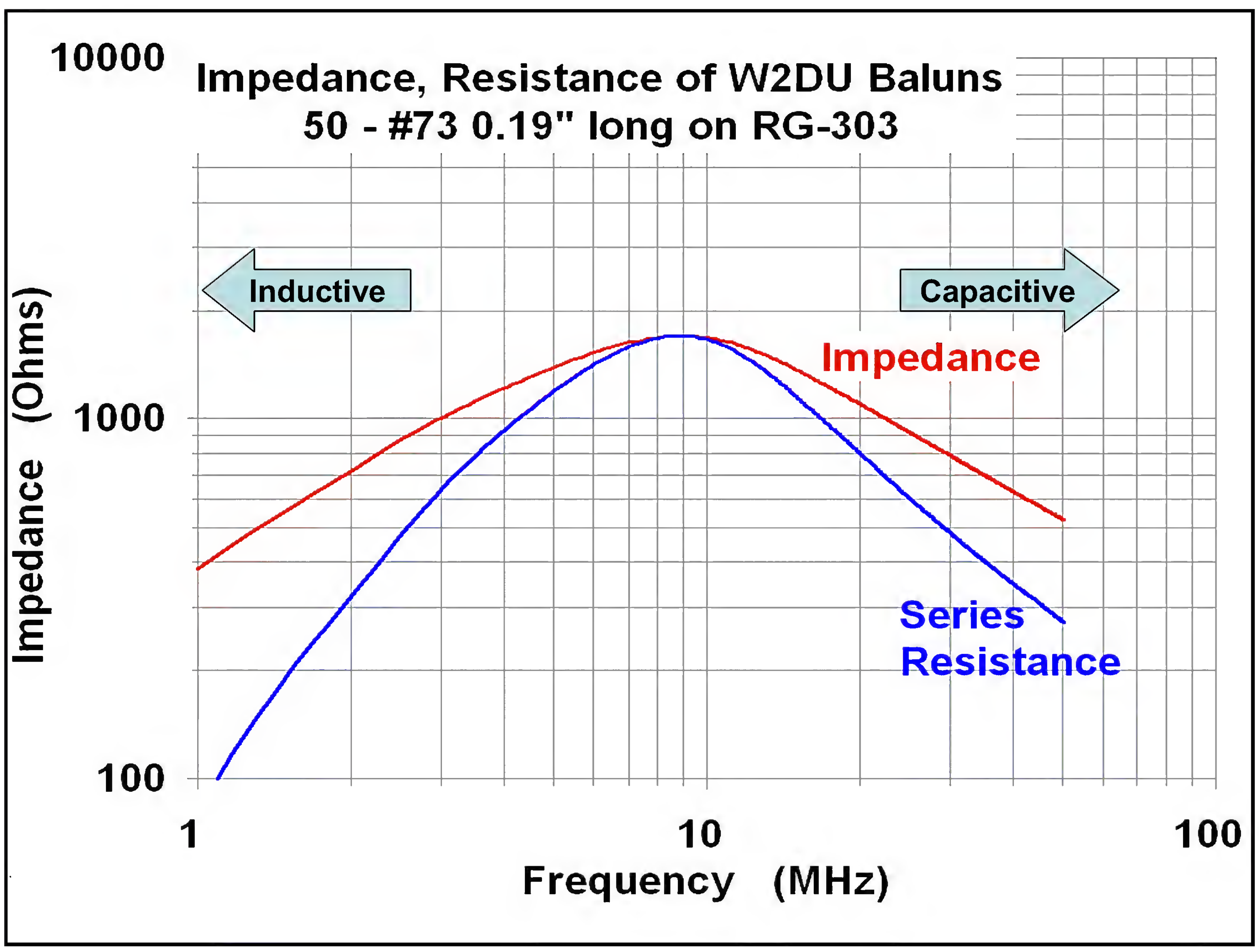
- Higher impedance is better!
  - Reduces common mode current
  - Reduces noise
  - Reduces interaction
  - Reduces RF in the shack
  - Reduces dissipation
- Resistance is better than reactance
  - Not sensitive to feedline length
  - Reactance can resonate with line

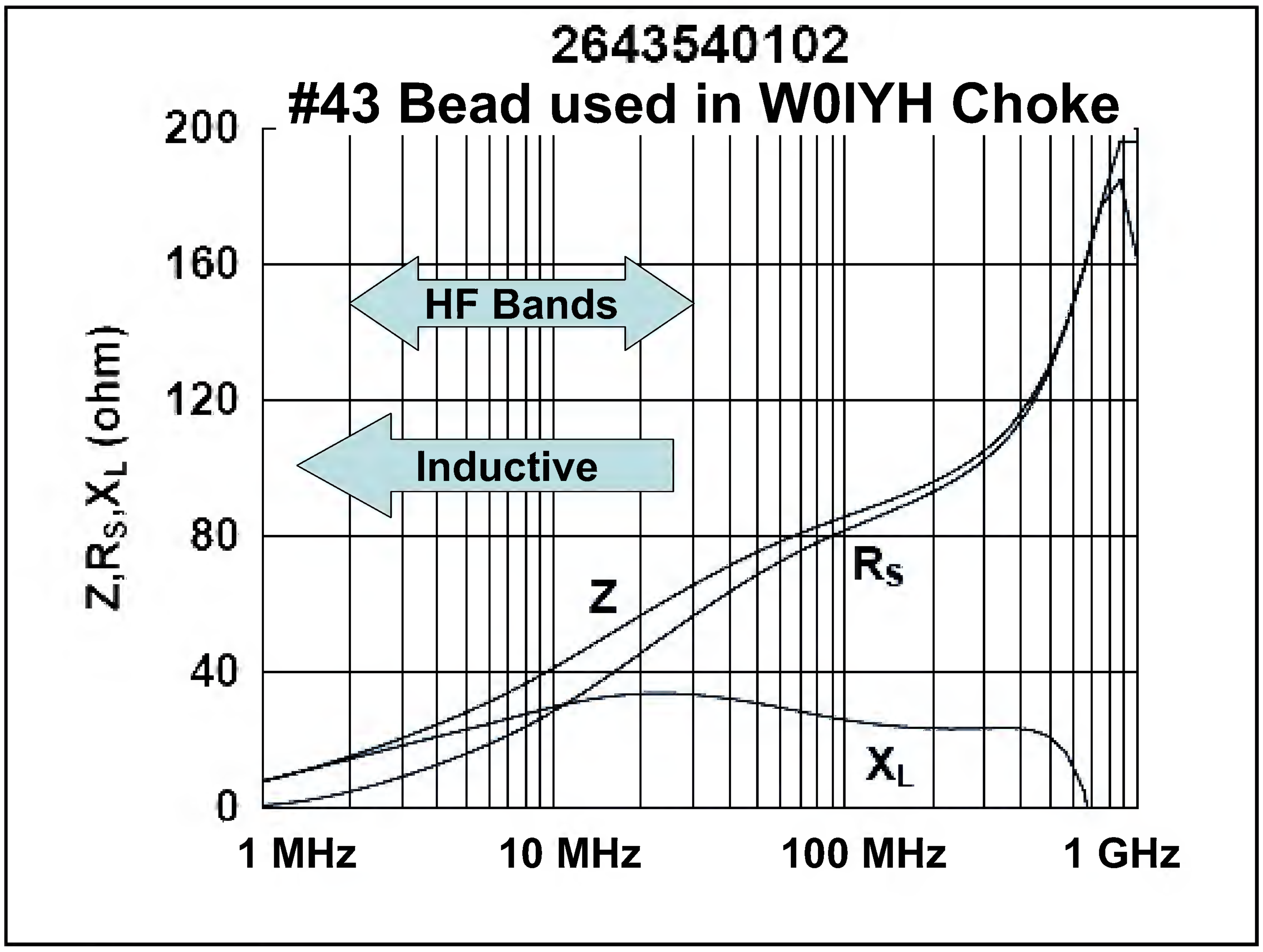
A “String of Beads” (W2DU, W0IYH Balun)



W2DU Choke

- A “string of beads” choke
- Original W2DU used #73 mix (good)
- Increasingly resistive above 3 MHz
  - Not very sensitive to feedline length
- Much better than bead of WØIYH choke
- But <u>many</u> more beads are needed
- #73 only made to fit RG58 or RG303





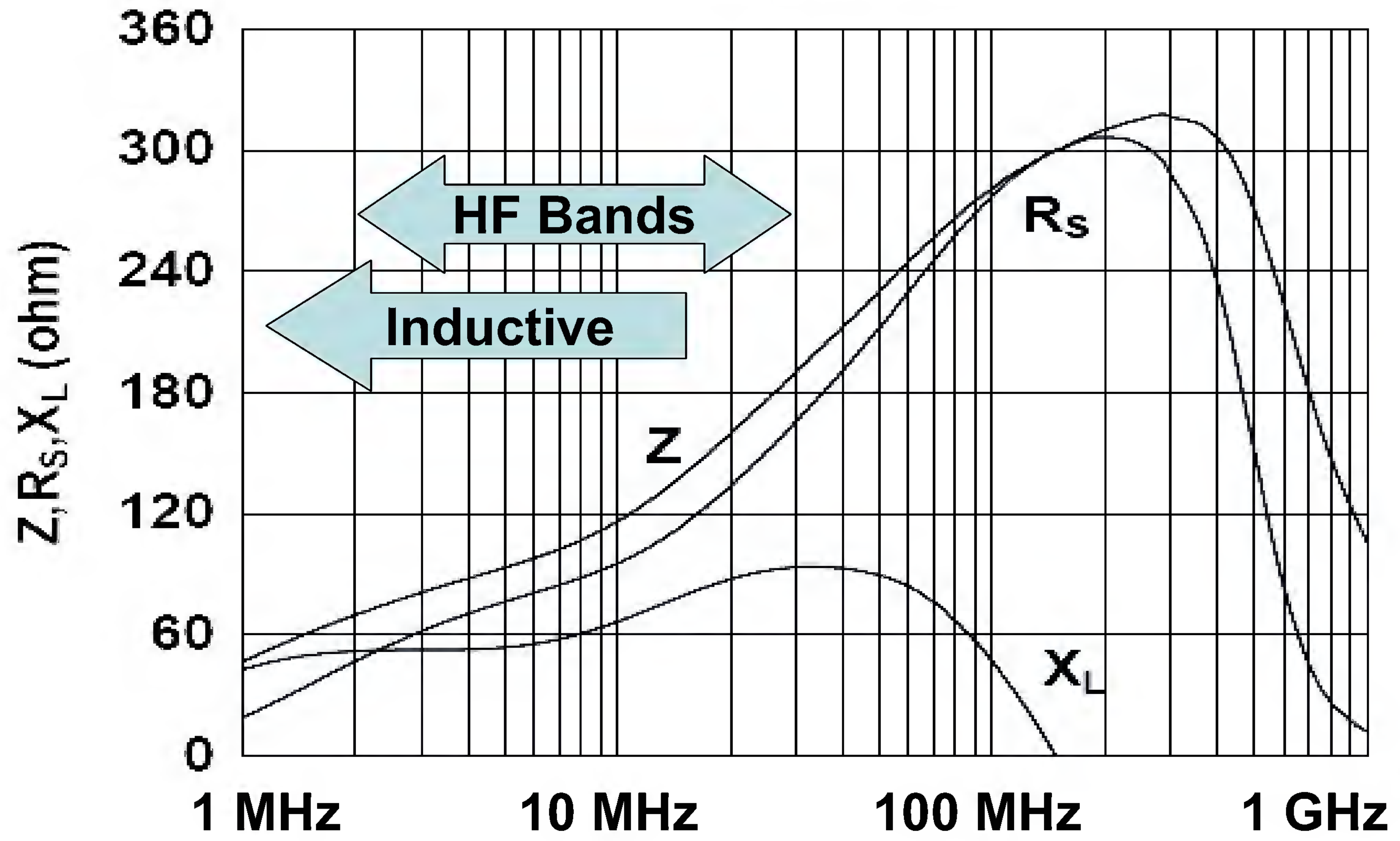
W0IYH Choke

- Also a “string of beads” choke
- Predominantly <u>inductive</u> below 25 MHz
  - Very sensitive to feedline length
  - Inductance resonates with a capacitive line
- Increasingly resistive above 25 MHz
  - Much less sensitive to feedline length
- Not very effective below 15 meters!

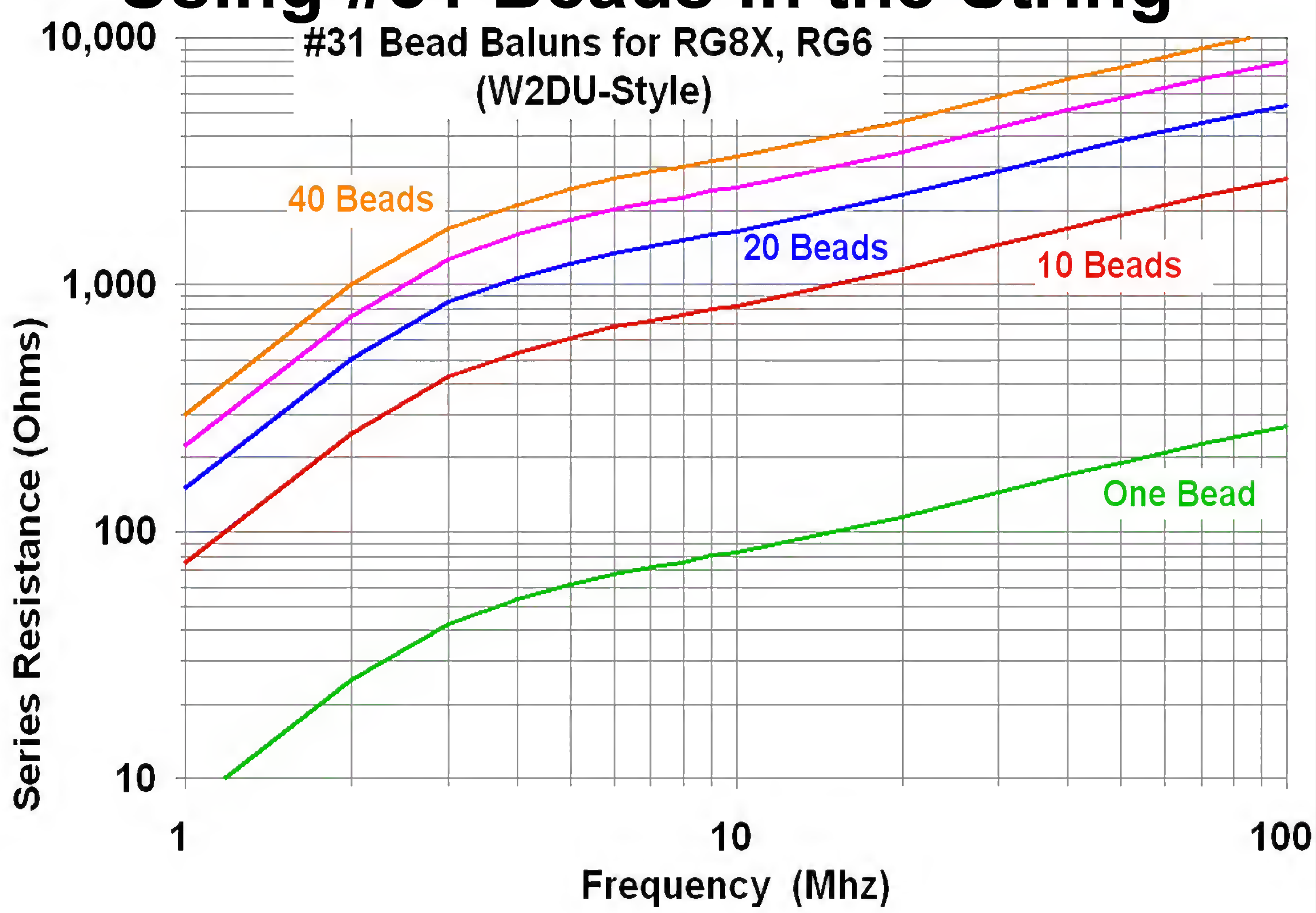
A #31 Bead for the String

(Fits RG8)

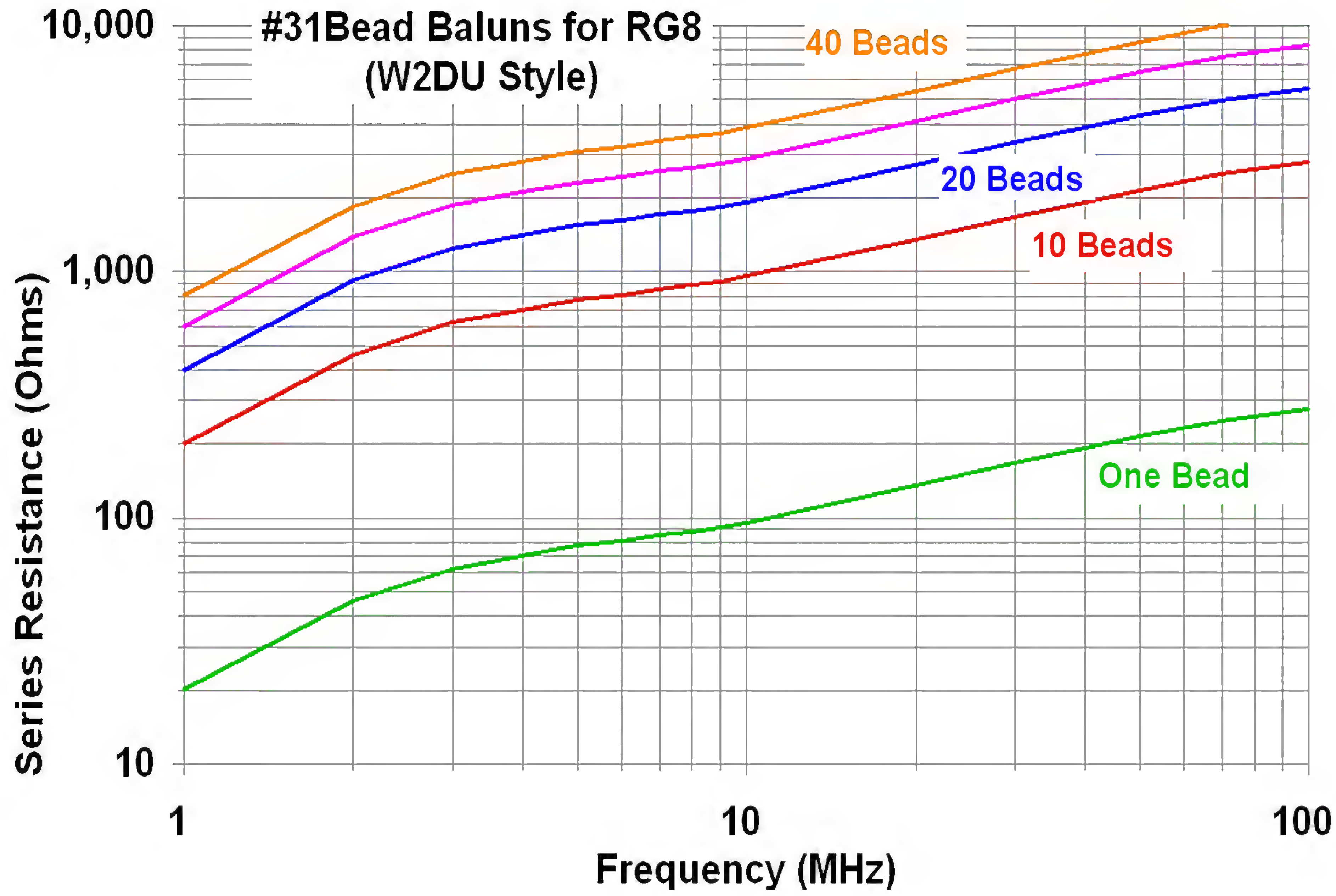
2631102002



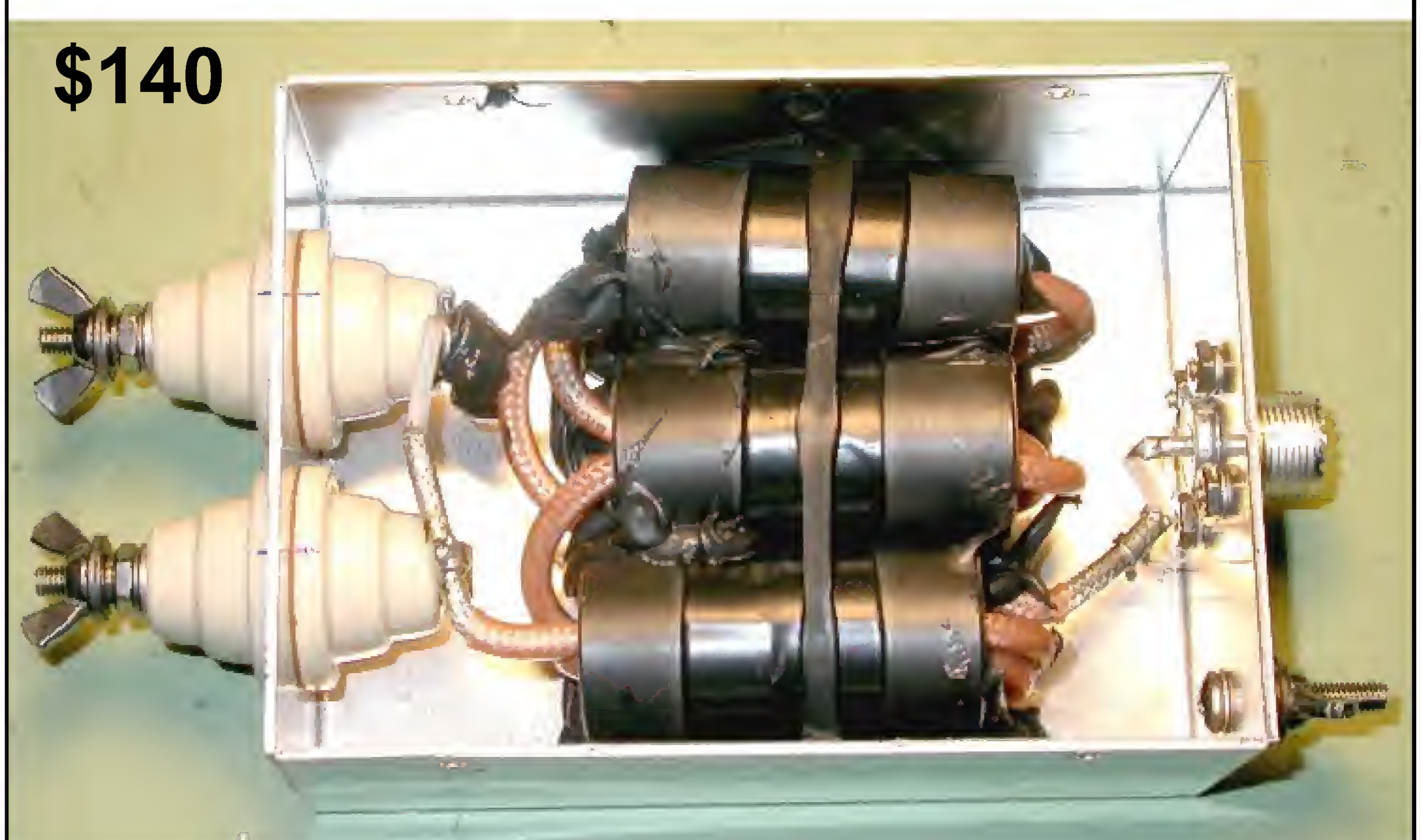
Using #31 Beads in the String



Using #31 Beads in the String



DX Engineering 50Ω Choke Balun



DX Engineering 200Ω – 50Ω Choke Balun

$130

What About Heat?

- Heat (Power) is I^2R
  - Make R large
  - I reduces in proportion to R
  - P reduces as I^2 so power (heat) is dropping twice as fast as R is increasing

What About Heat?

- Heat is not a problem if R (the choking impedance) is large enough
- How large is enough?
  - At maximum ham power, 5,000 Ω allows a very comfortable margin

See K9YC's Choke Cookbook (Chapter 7 in the RFI Tutorial) for specific recommendations

http://audiosystemsgroup.com/RFI-Ham.pdf

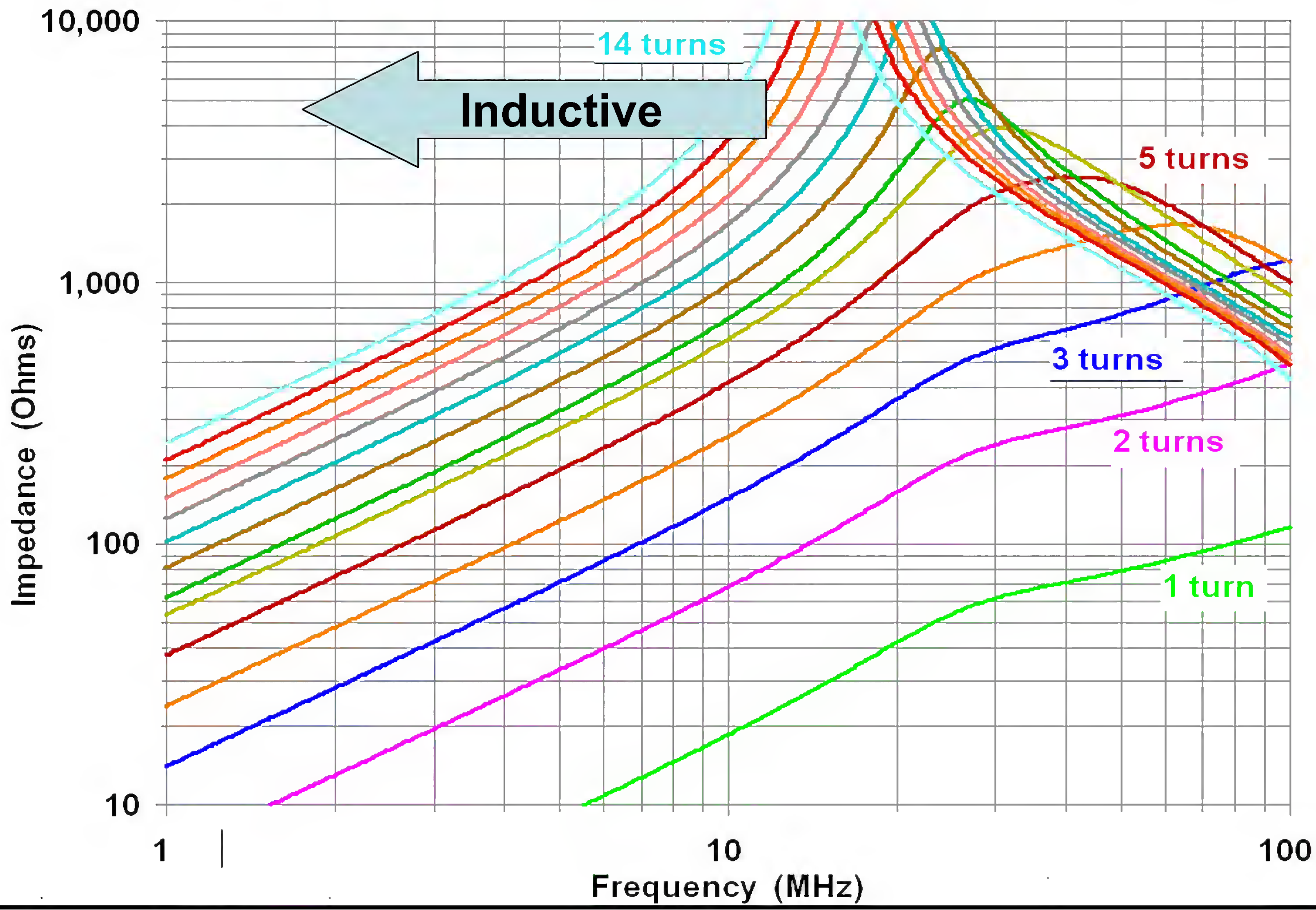
W2FMI Choke Balun
(Discontinued by DX Engineering)

WXØB Still Sells Them – $96-$126

Twin Lead Chokes

- Twin lead has 30-40% leakage flux
  - Choke sees at least 30-40% of transmit power plus the common mode voltage
  - Much more likely to overheat
  - More likely to saturate (harmonics, IMD, splatter, choking impedance drops)
- Must use low loss cores #61, #67

Single Wire Chokes on a #61 toroid



Twin Lead (W2FMI) Choke

- Wound on #61 Material
- Predominantly <u>inductive</u> below 20 MHz
  - Very sensitive to feedline length
  - Inductance resonates with a capacitive line
- Twin-lead construction puts 30-40% of transmit power in ferrite
  - Loss
  - Overheating
  - Distortion (splatter, harmonics)
- Not much choking Z below 10 MHz

K9YC Chokes (Improved W2DU Chokes)

An 80/40 Fan Dipole


An 80/40 Fan Dipole

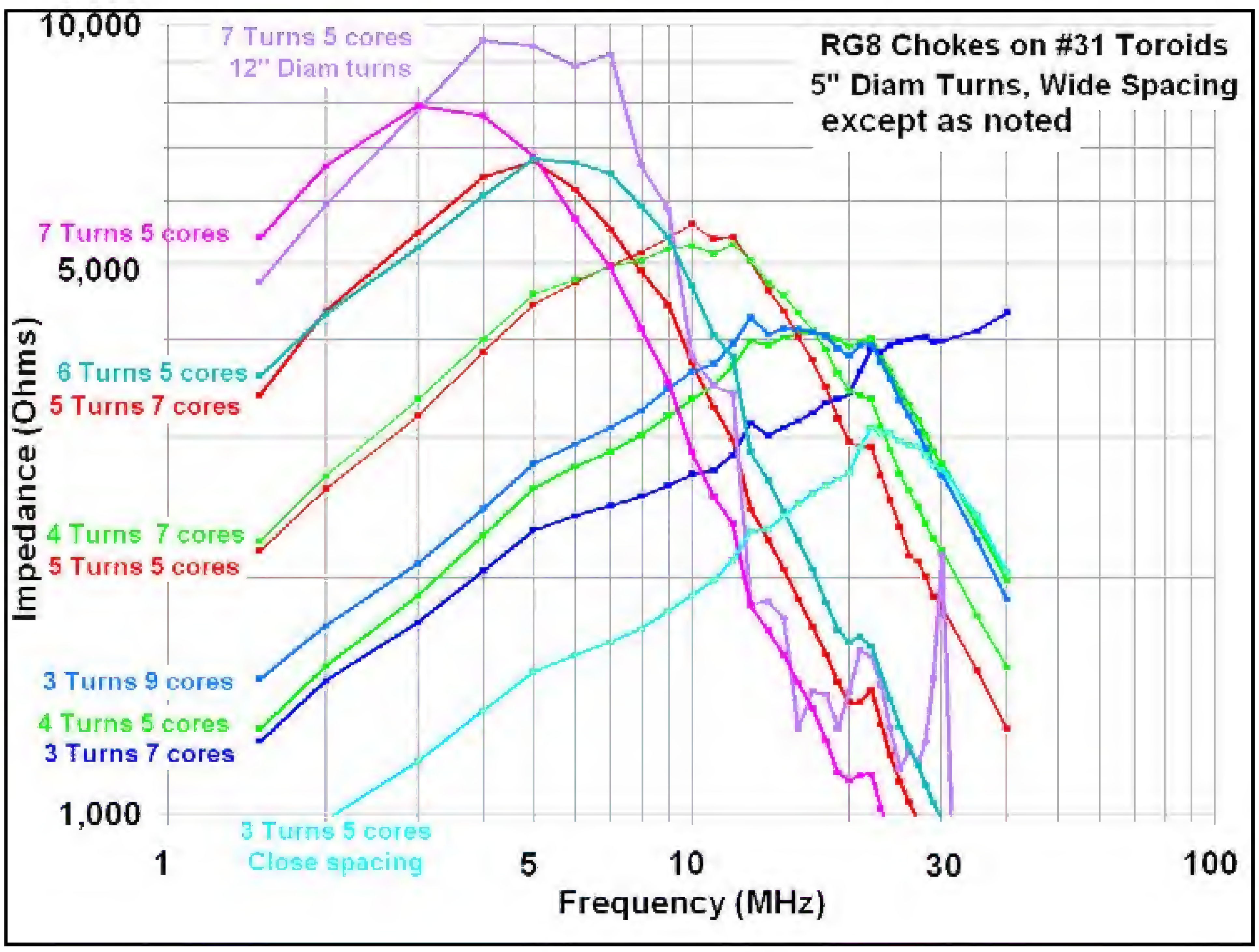

Closely Spaced Turns for an 80/40 Fan Dipole

Why Use Wound Chokes

- Impedance increases as the square of the number of turns
- Inductance increases as the square of the number of turns
- Capacitance increases with more turns
  - Capacitance through ferrite core
  - Capacitance between turns
- So Resonant frequency drops
  - With 1-2 turns it's a VHF choke
  - With 4 – 8 turns it's an HF choke

Wide or Close Spacing?

- Close spacing lowers resonant frequency
  - More capacitance
  - More inductance
- Close spacing may be better below 10 MHz
- Wide spacing usually best above 10 MHz
- Study the K9YC data and Cookbook for specific applications

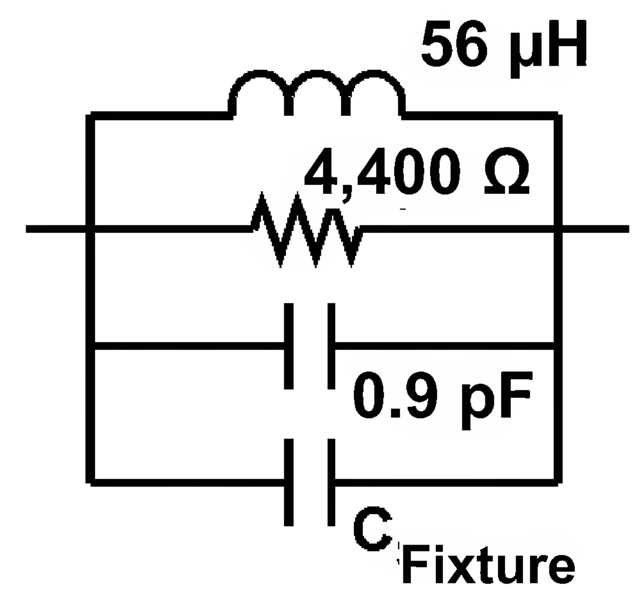


The Measurement Problem

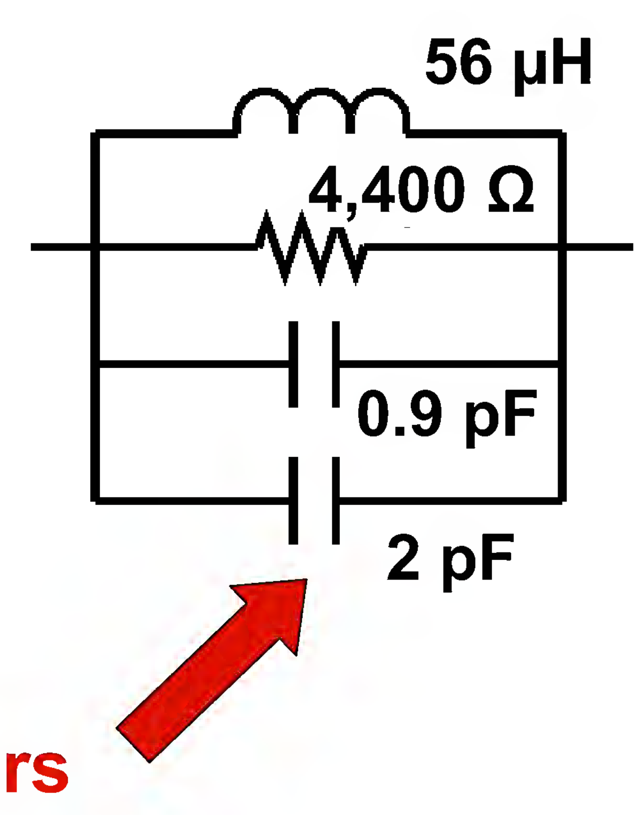
Measuring Coax Chokes

- Very difficult to measure
- Traditional "reflection" measurements don't work
  - Poor accuracy if 5 ohms > Zx > 500 ohms
- Stray capacitance of fixture causes additional errors
  - Some VNA's that claim to subtract it out don't
- **A lot of smart people have missed all this!**

What are we Trying to Measure?



What are we Trying to Measure?



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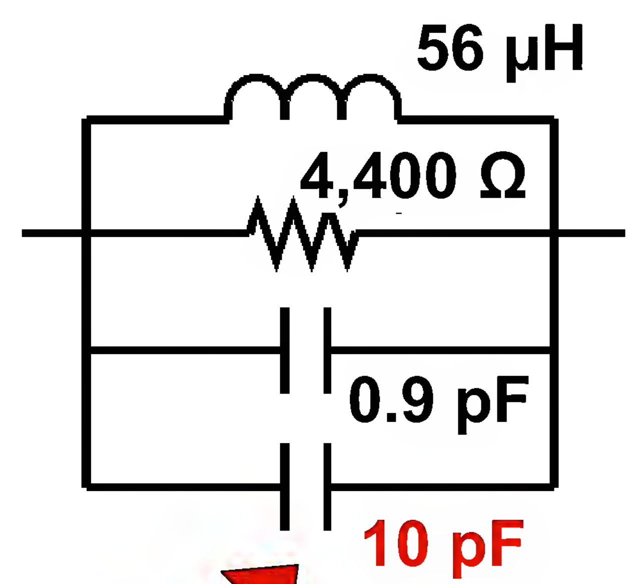
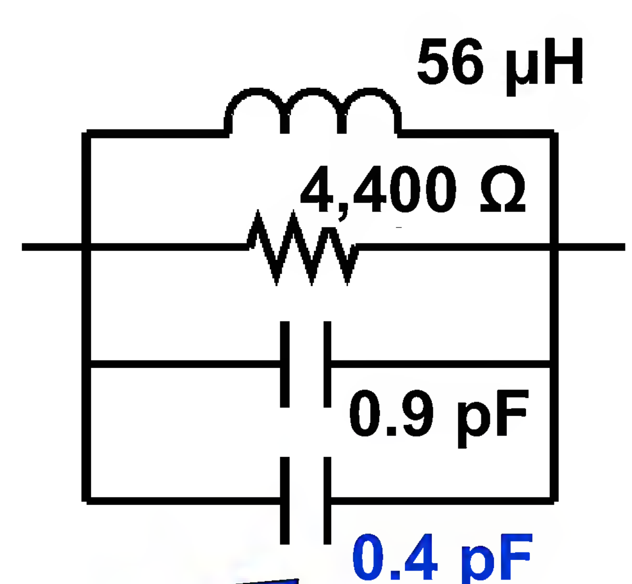
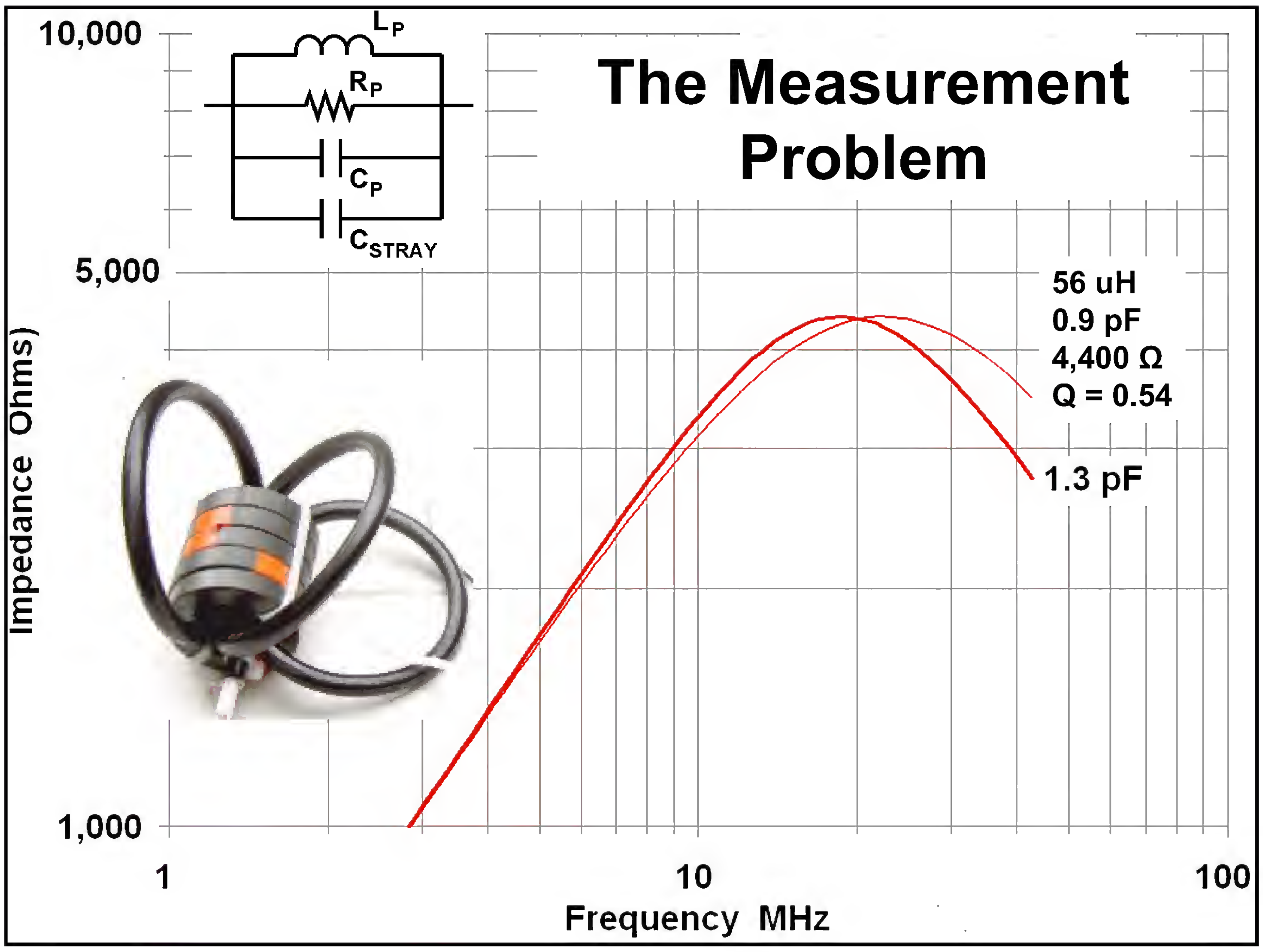


Typical “antenna” analyzers

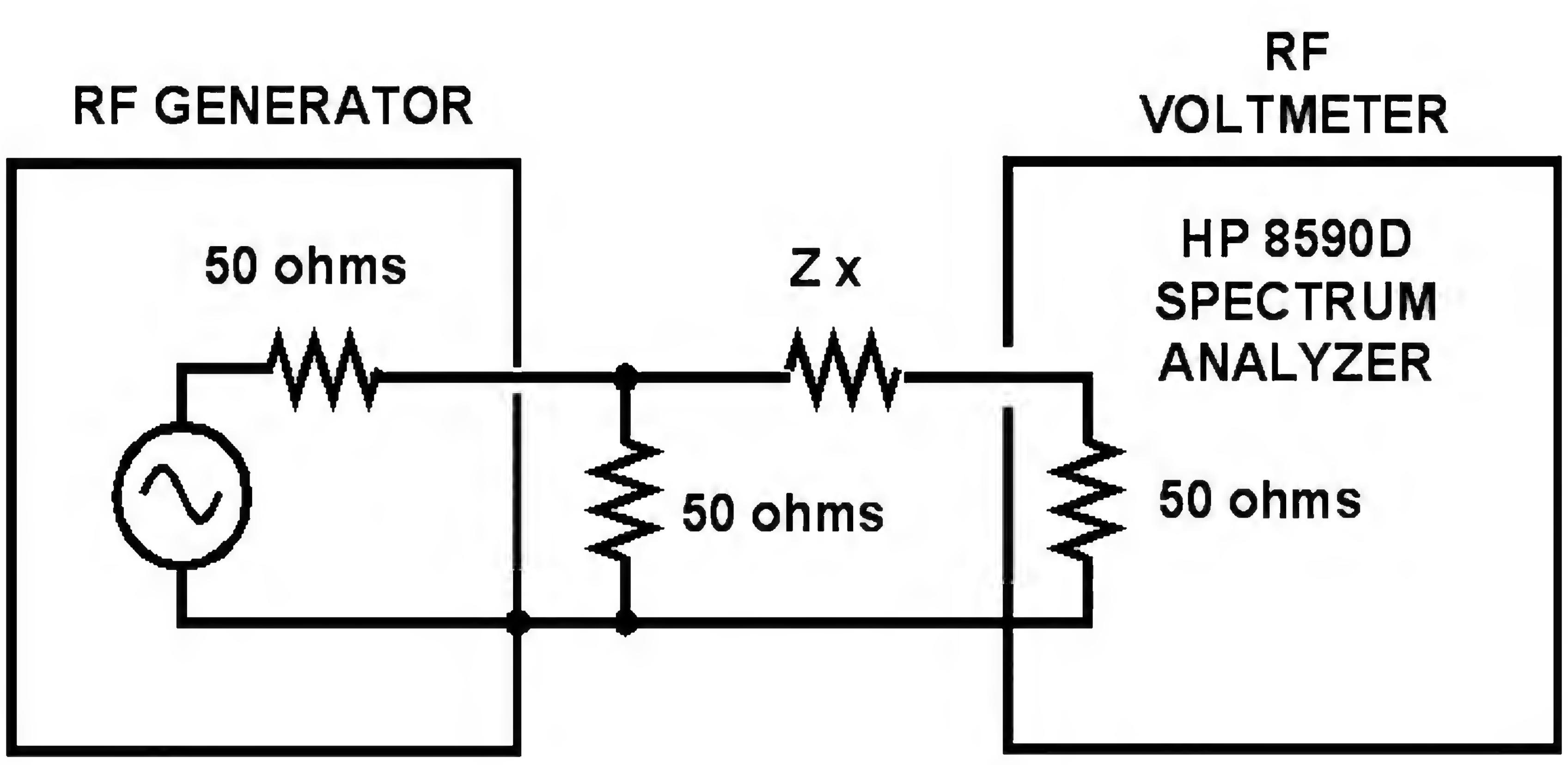
What are we Trying to Measure?



My measurement setup

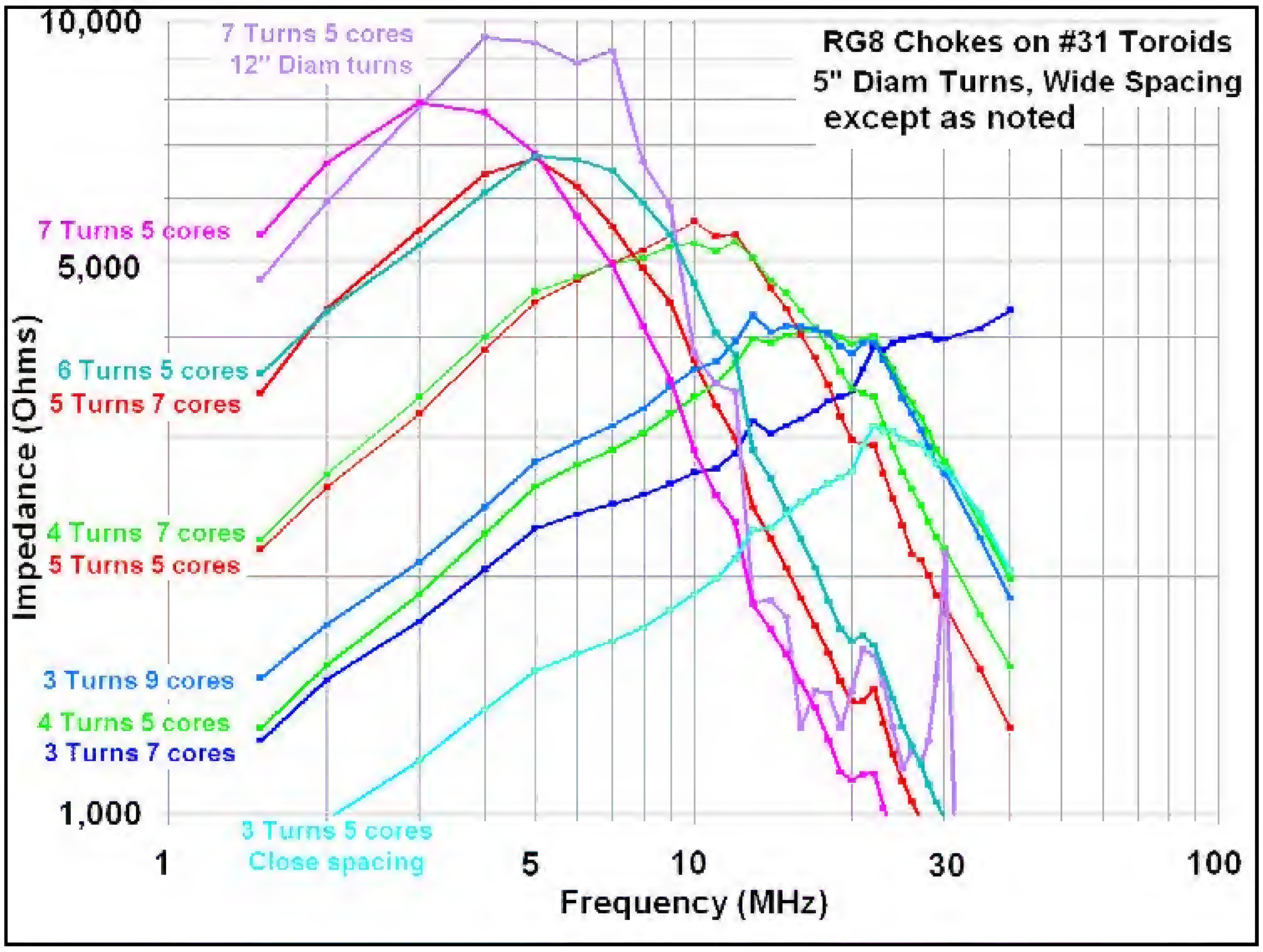


Measuring Coax Chokes

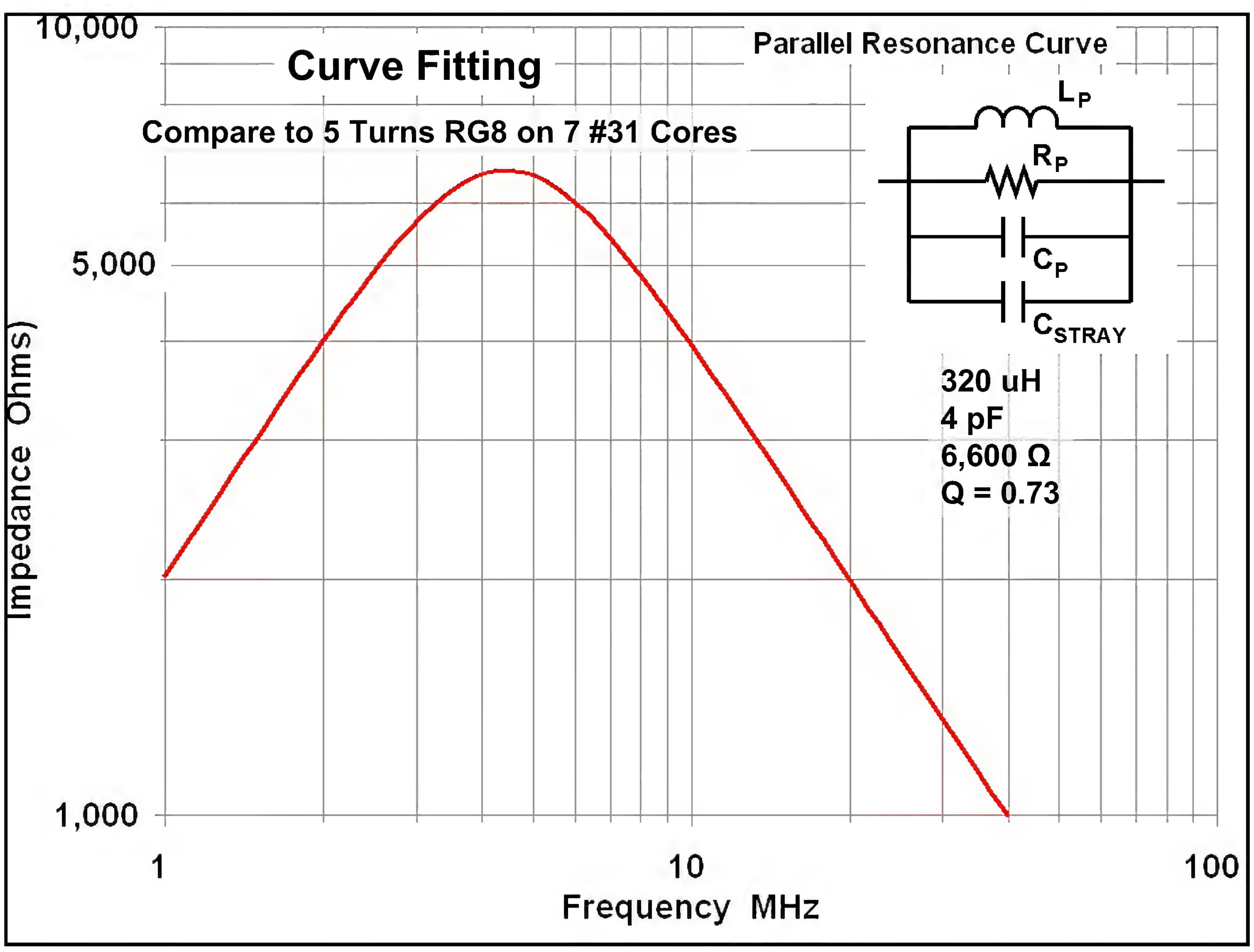



8590D
0.0

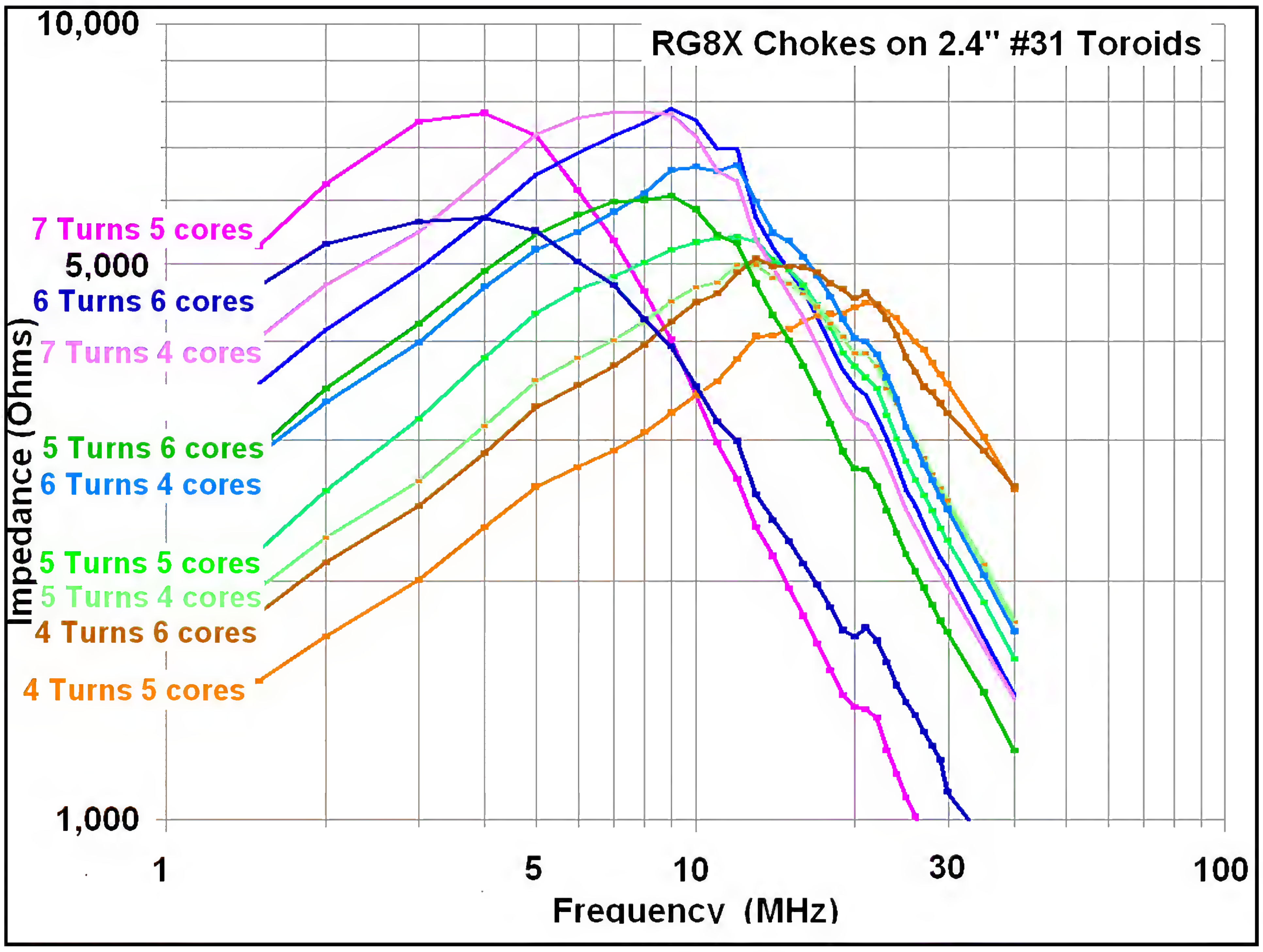

8590D
0.8
10.0

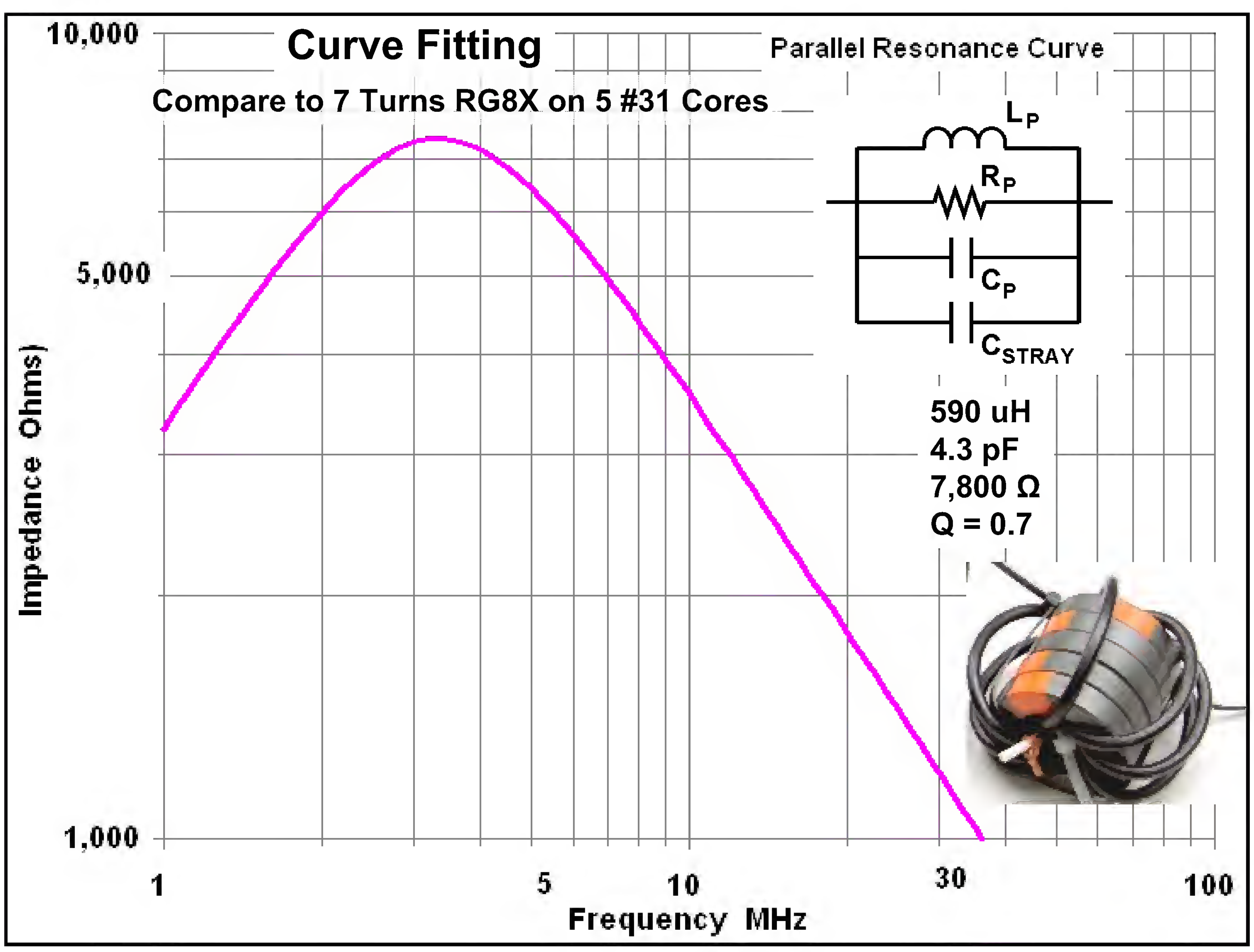


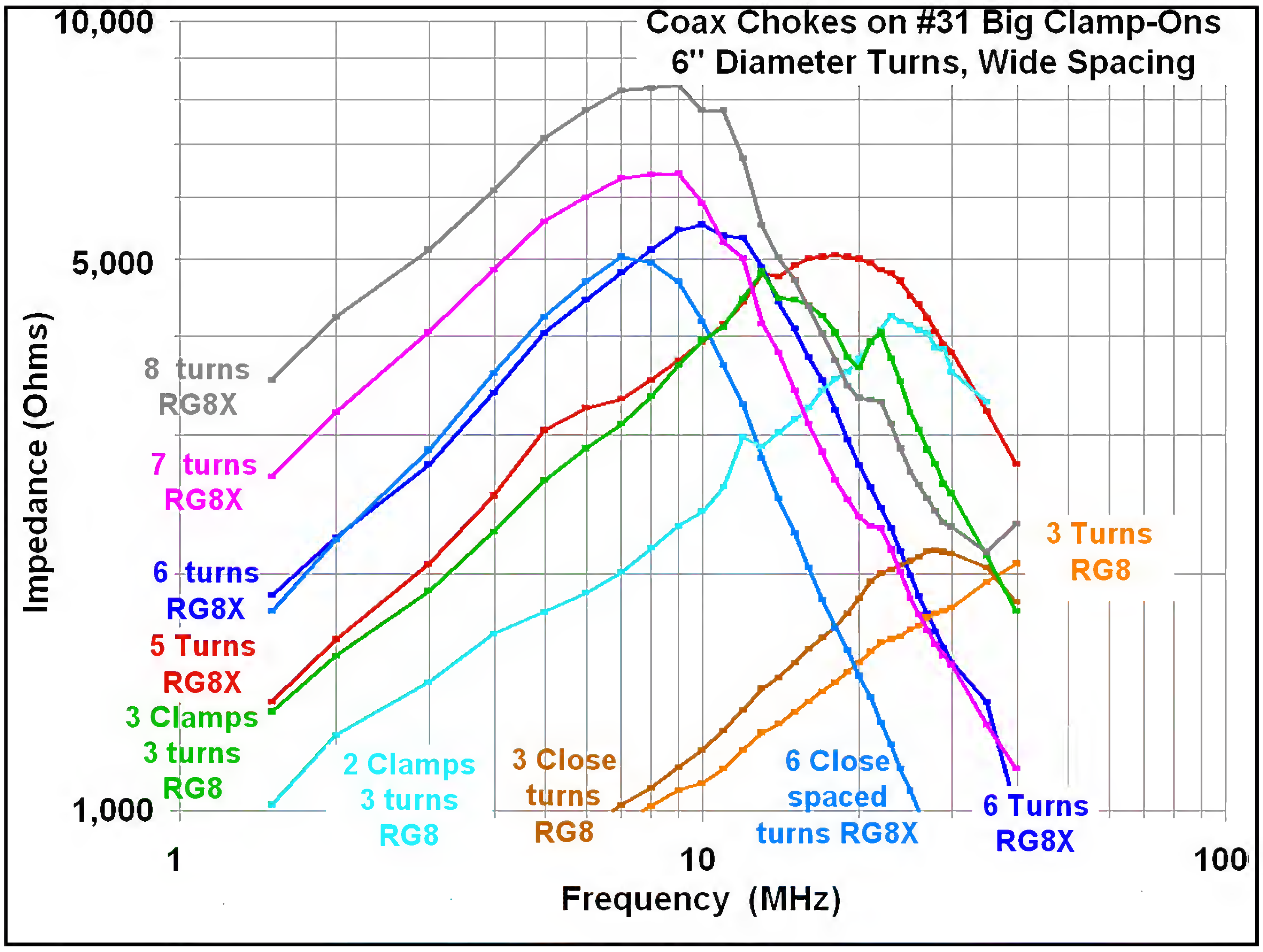
RG8 Chokes on #31 Toroids
5" Diam Turns, Wide Spacing
except as noted
7 Turns 5 cores
12" Diam turns
7 Turns 5 cores
6 Turns 5 cores
5 Turns 7 cores
4 Turns 7 cores
5 Turns 5 cores
3 Turns 9 cores
4 Turns 5 cores
3 Turns 7 cores
3 Turns 5 cores
Close spacing
10,000
5,000
1,000
Impedance (Ohms)
1
5
10
30
100
Frequency (MHz)

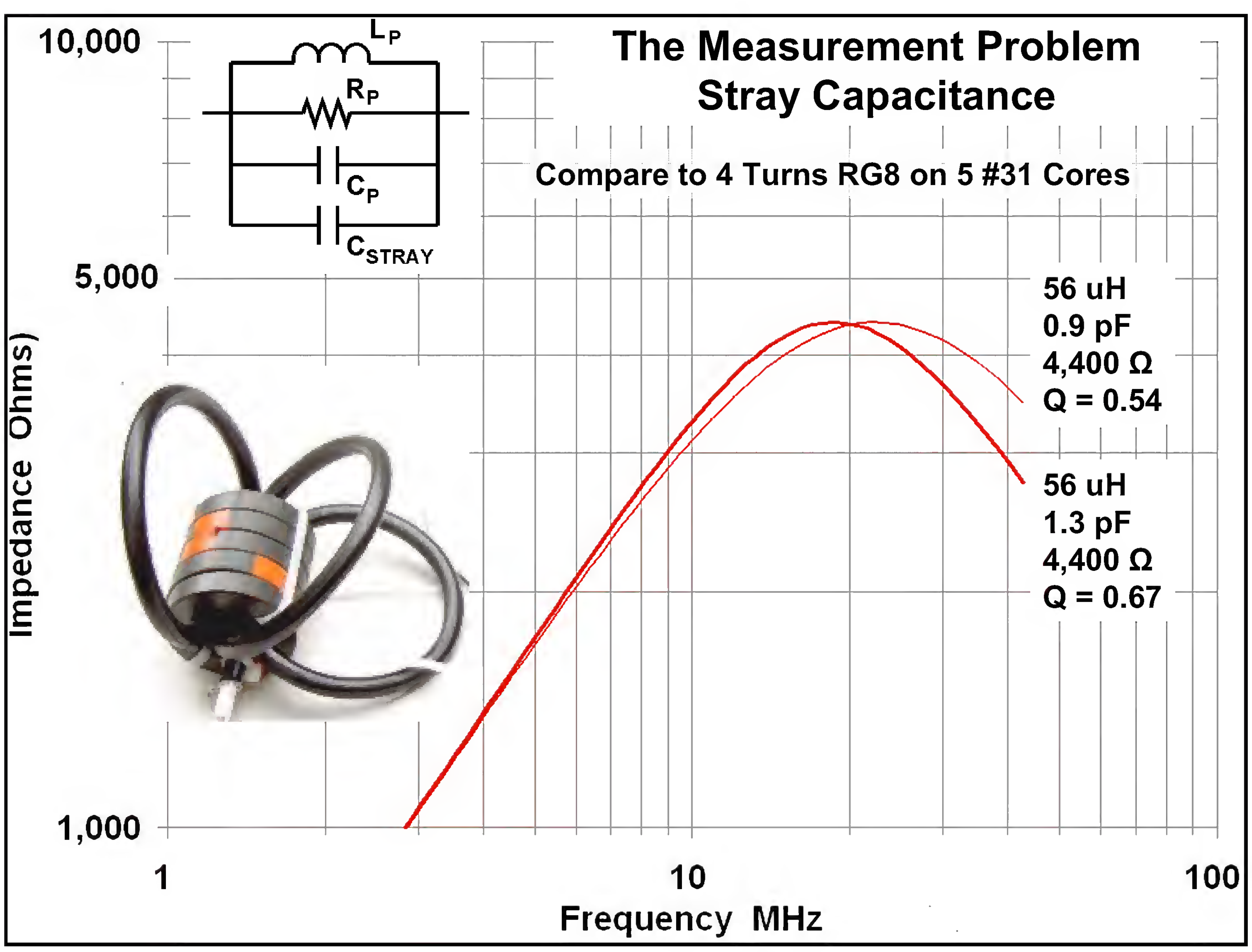


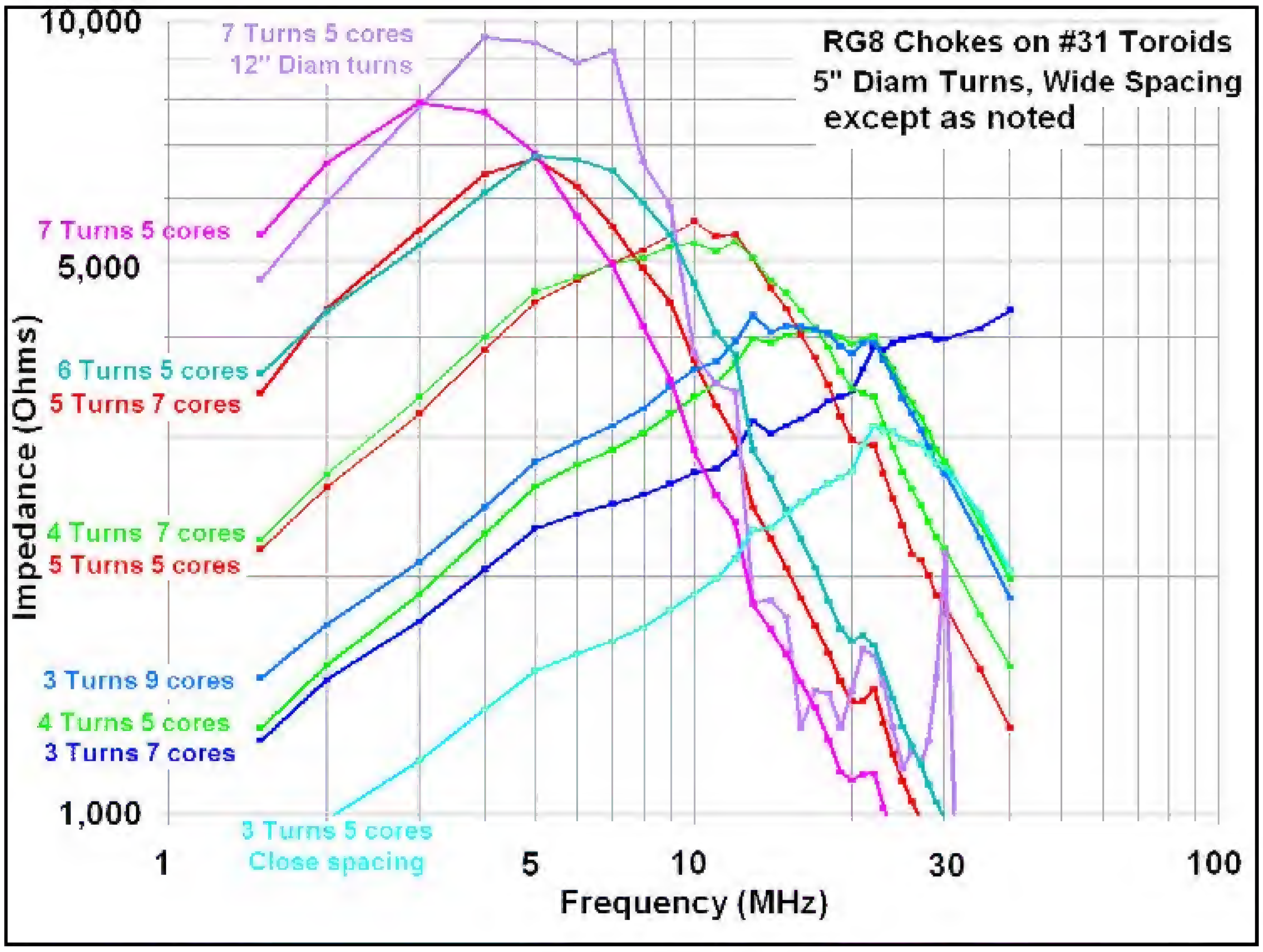
Curve Fitting
Compare to 5 Turns RG8 on 7 #31 Cores
Parallel Resonance Curve
L_P
R_P
C_P
C_{STRAY}
320 uH
4 pF
6,600 Ω
Q = 0.73
10,000
5,000
1,000
Impedance Ohms)
1
10
100
Frequency MHz


RG8X Chokes on 2.4" #31 Toroids
10,000
5,000
1,000
Impedance (Ohms)
7 Turns 5 cores
6 Turns 6 cores
7 Turns 4 cores
5 Turns 6 cores
6 Turns 4 cores
5 Turns 5 cores
5 Turns 4 cores
4 Turns 6 cores
4 Turns 5 cores
1
5
10
30
100
Frequency (MHz)

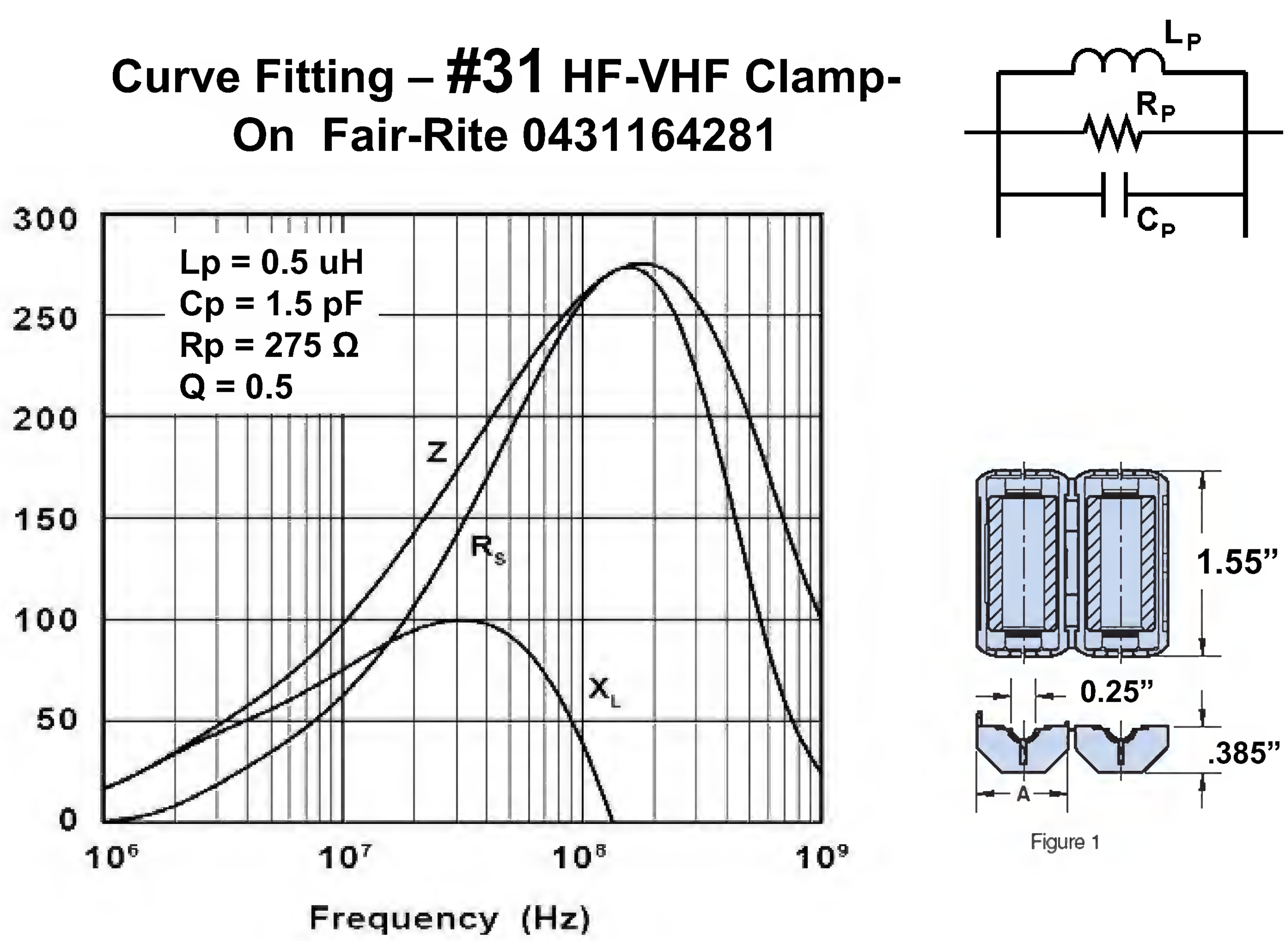

Curve Fitting
Compare to 7 Turns RG8X on 5 #31 Cores
Parallel Resonance Curve
L_P
R_P
C_P
C_{STRAY}
590 uH
4.3 pF
7,800 Ω
Q = 0.7
10,000
5,000
1,000
Impedance Ohms
1
5
10
30
100
Frequency MHz


Coax Chokes on #31 Big Clamp-Ons
6" Diameter Turns, Wide Spacing
10,000
5,000
1,000
Impedance (Ohms)
8 turns RG8X
7 turns RG8X
6 turns RG8X
5 Turns RG8X
3 Clamps 3 turns RG8
2 Clamps 3 turns RG8
3 Close turns RG8
6 Close spaced turns RG8X
6 Turns RG8X
3 Turns RG8
1
10
100
Frequency (MHz)

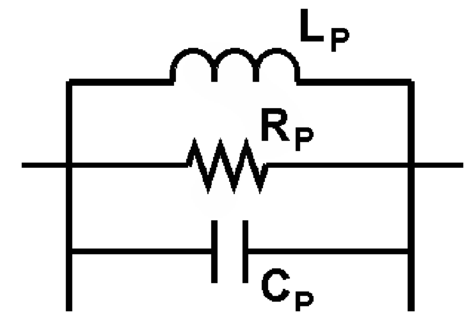

The Measurement Problem
Stray Capacitance
Compare to 4 Turns RG8 on 5 #31 Cores
L_P
R_P
C_P
C_{STRAY}
10,000
5,000
1,000
Impedance (Ohms)
56 uH
0.9 pF
4,400 Ω
Q = 0.54
56 uH
1.3 pF
4,400 Ω
Q = 0.67
1
10
100
Frequency MHz

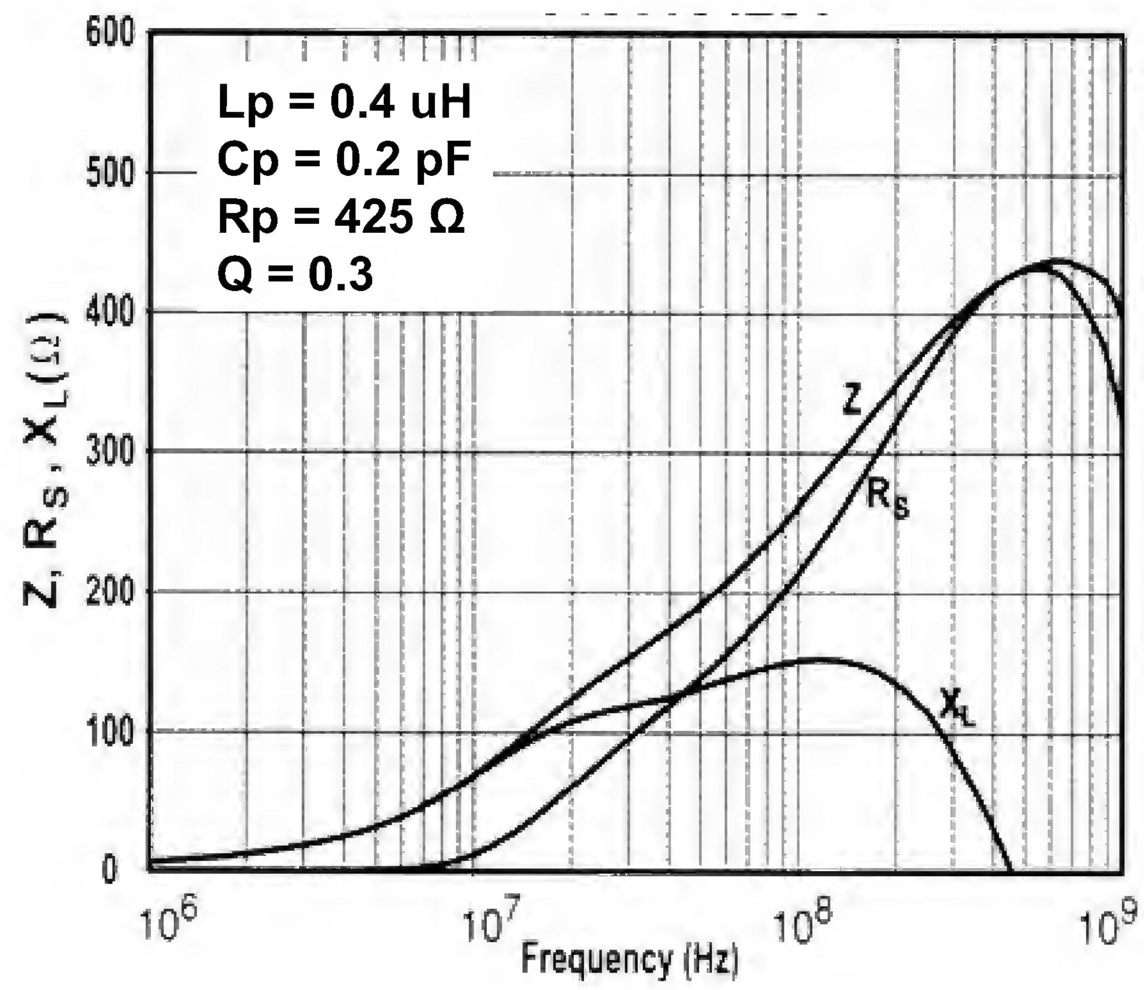


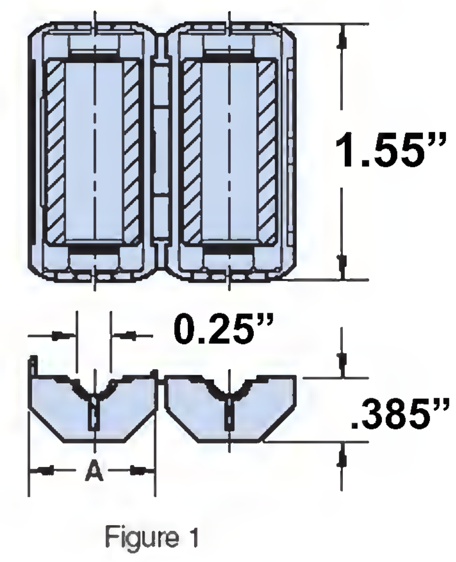
Curve Fitting – #31 HF-VHF Clamp-On Fair-Rite 0431164281



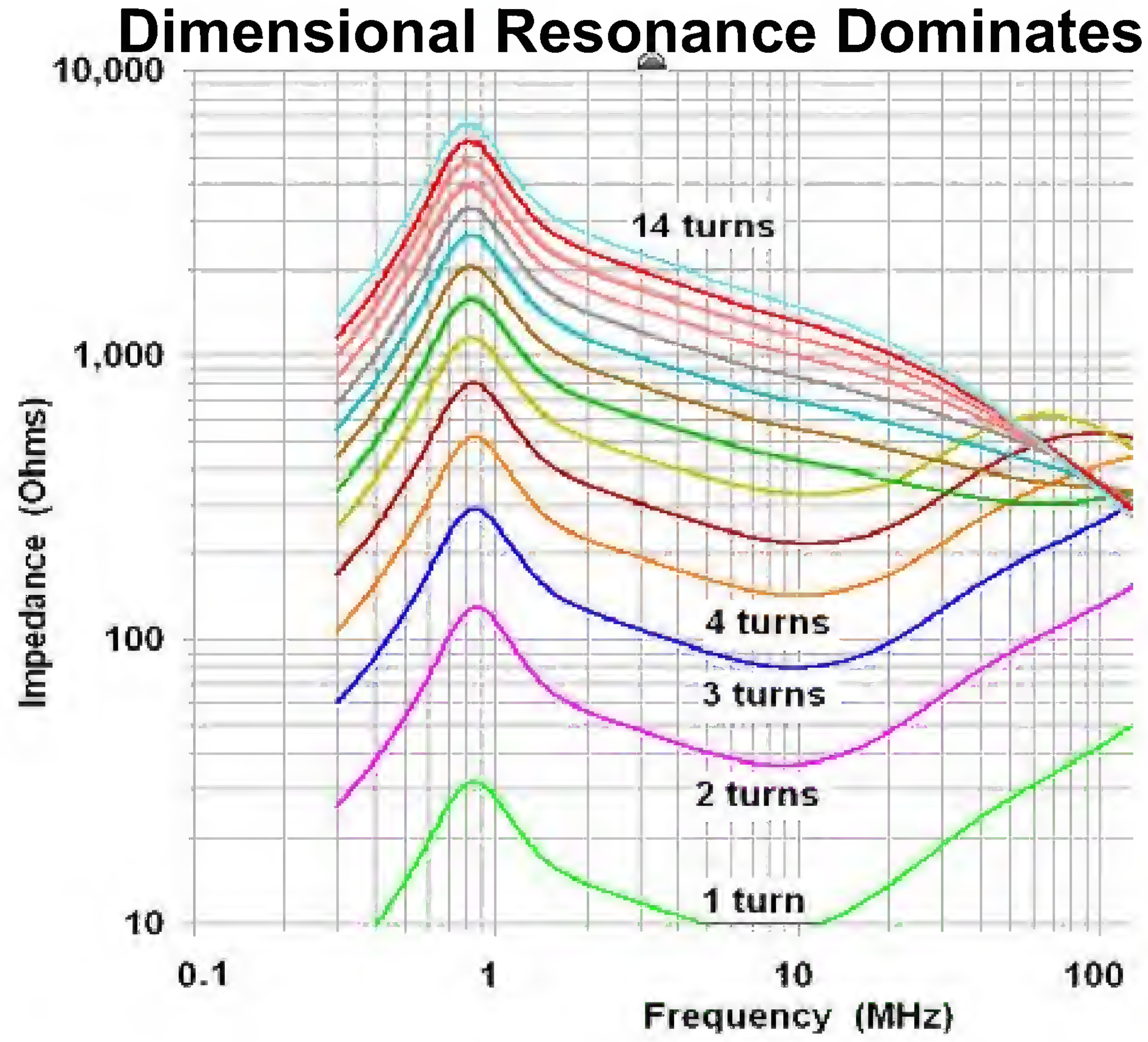
Curve Fitting – #61 UHF Clamp-On Fair-Rite 0461164281

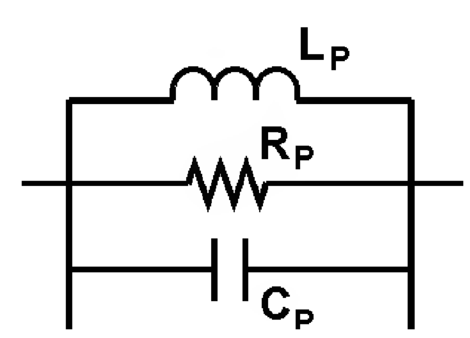






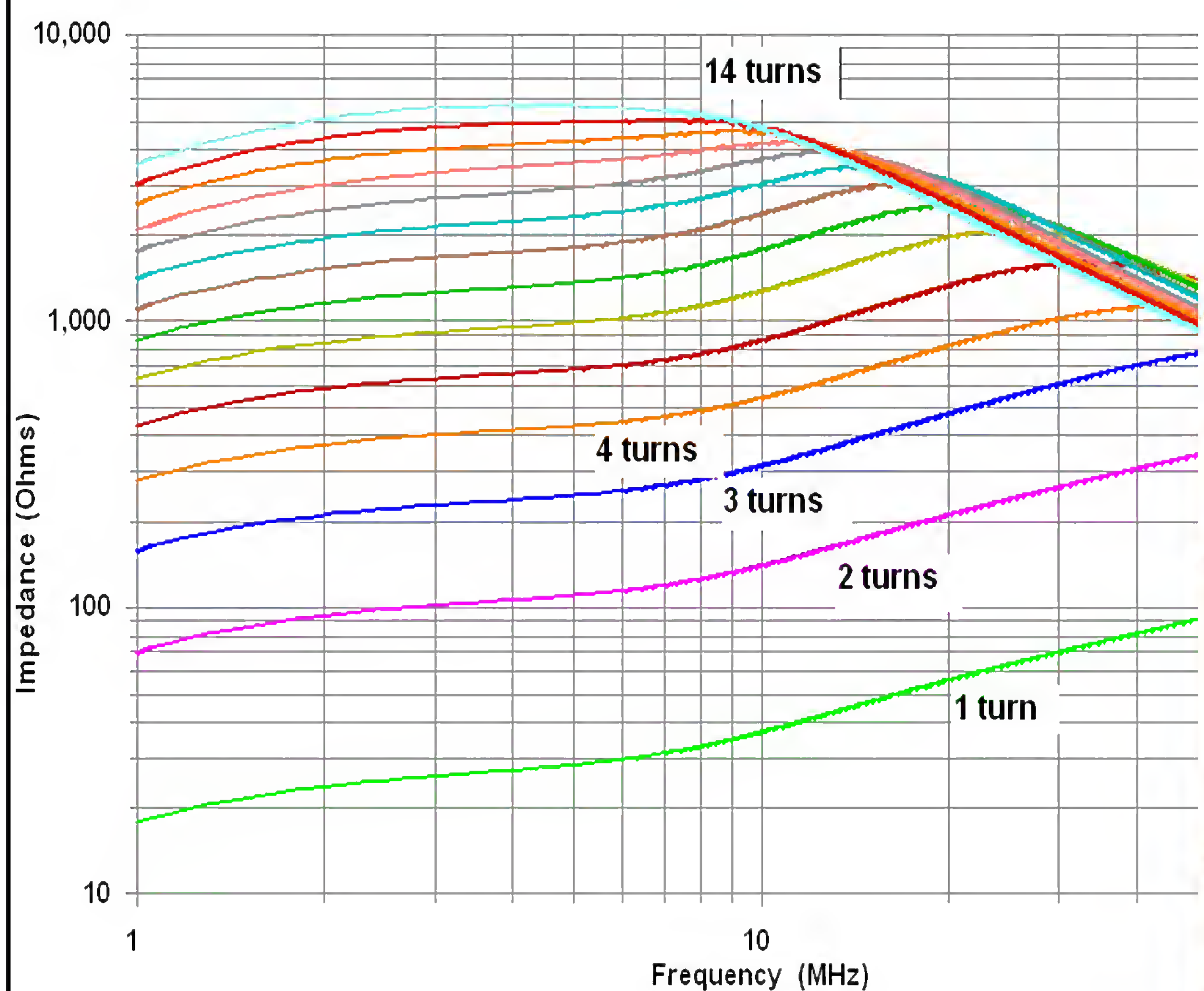
Curve Fitting –14 turns on #78 Toroid Dimensional Resonance Dominates

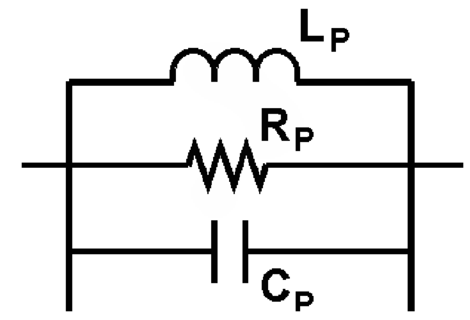




Lp = 700 uH
Cp = 60 pF
Rp = 6,500 Ω
Q = 1.9

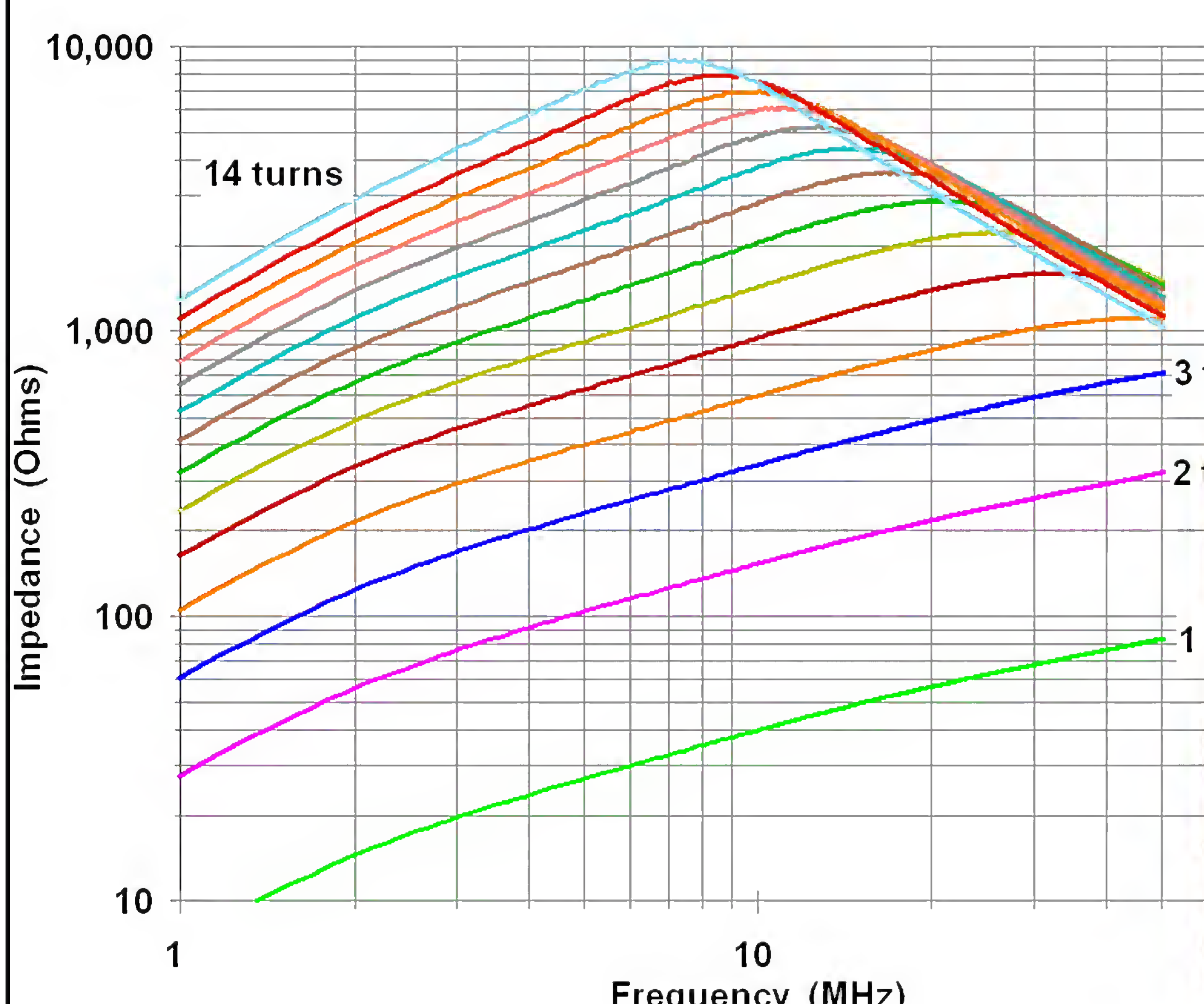
Curve Fitting –14 turns on #31 Toroid

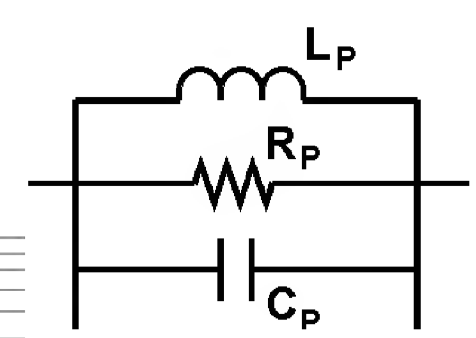




Lp = 650 uH
Cp = 2.2 pF
Rp = 5,800 Ω
Q = 0.34

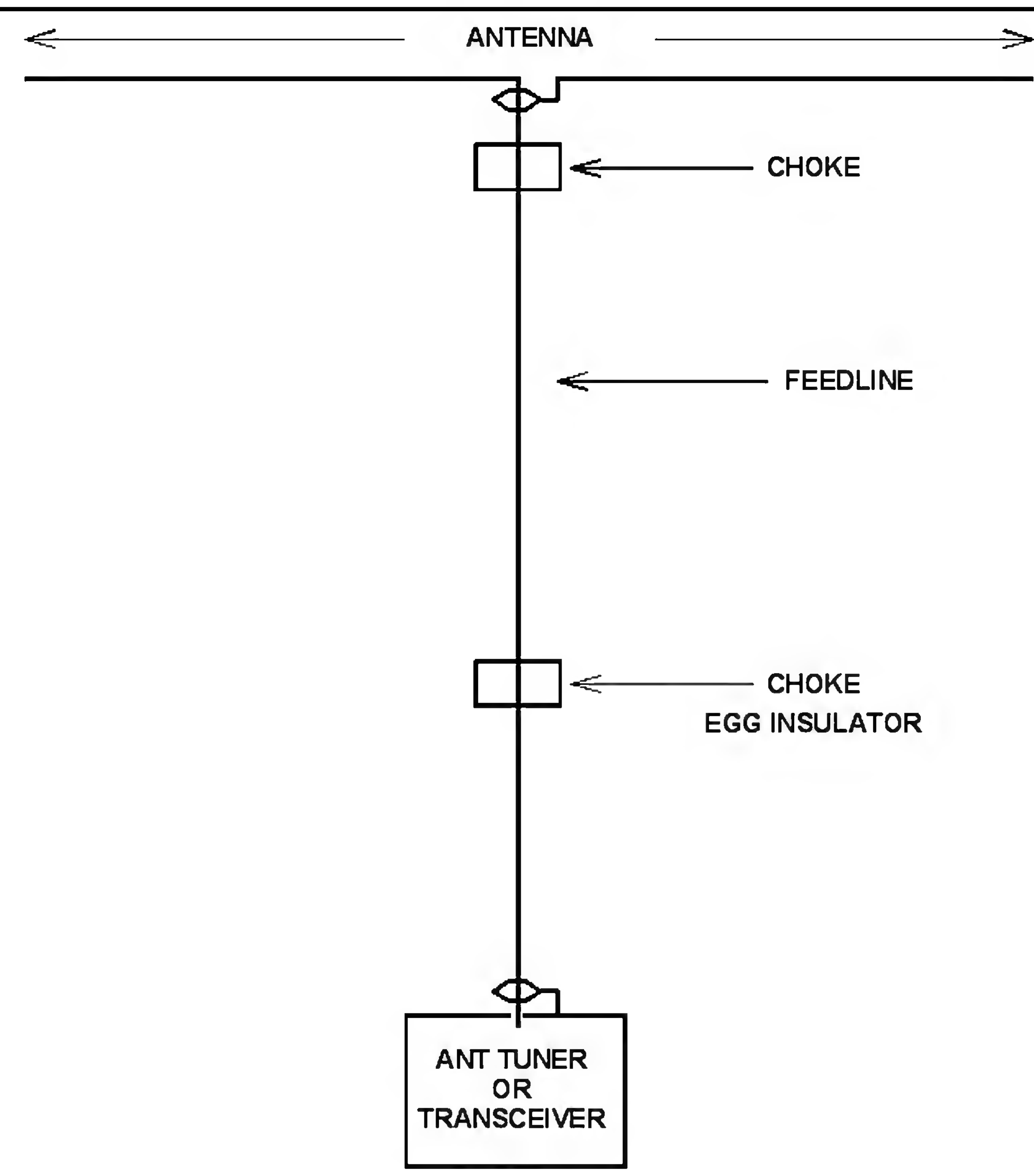
Curve Fitting –14 turns on #43 Toroid



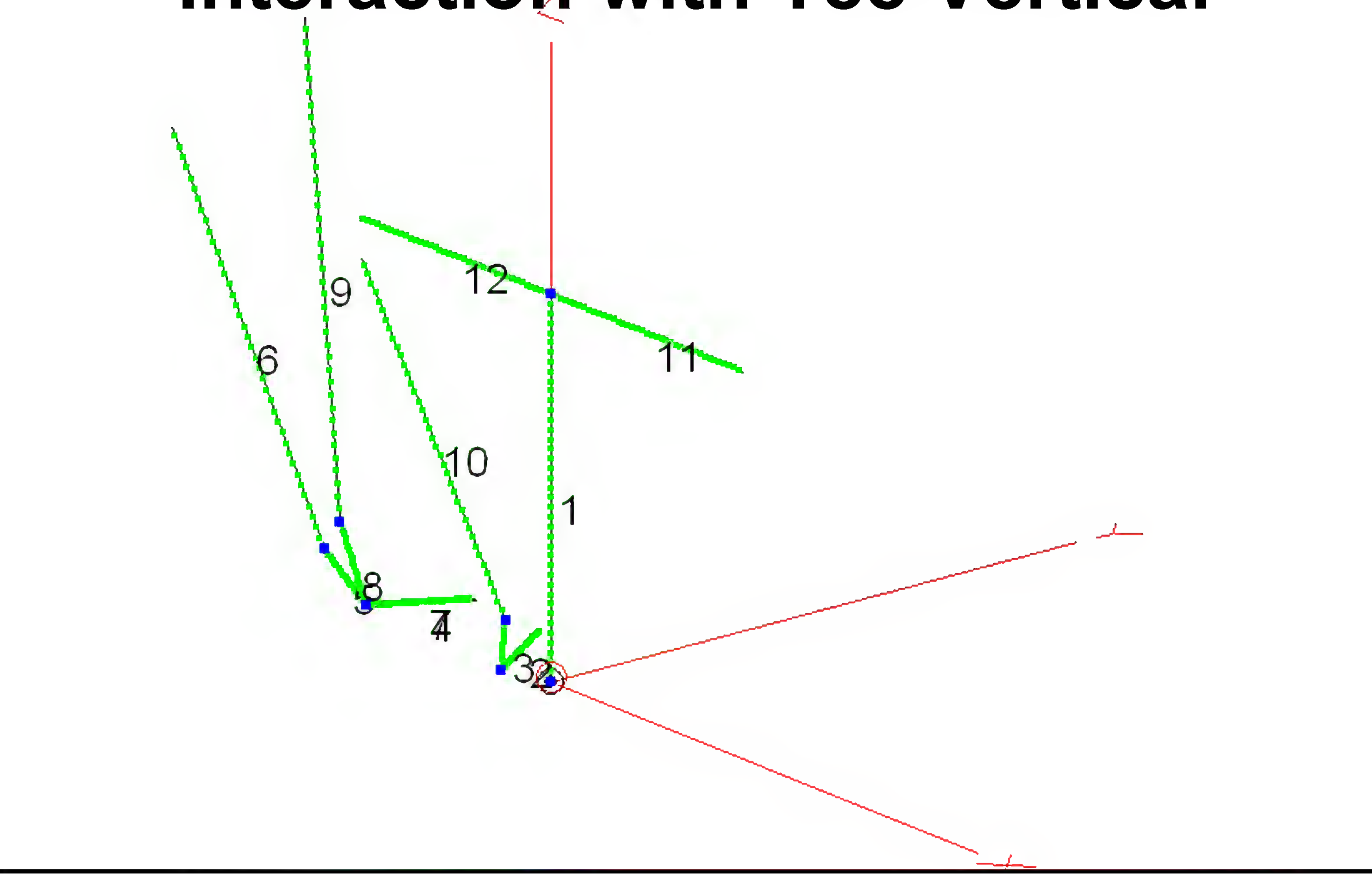


Lp = 210 uH
Cp = 1.9 pF
Rp = 9,000 Ω
Q = 0.86

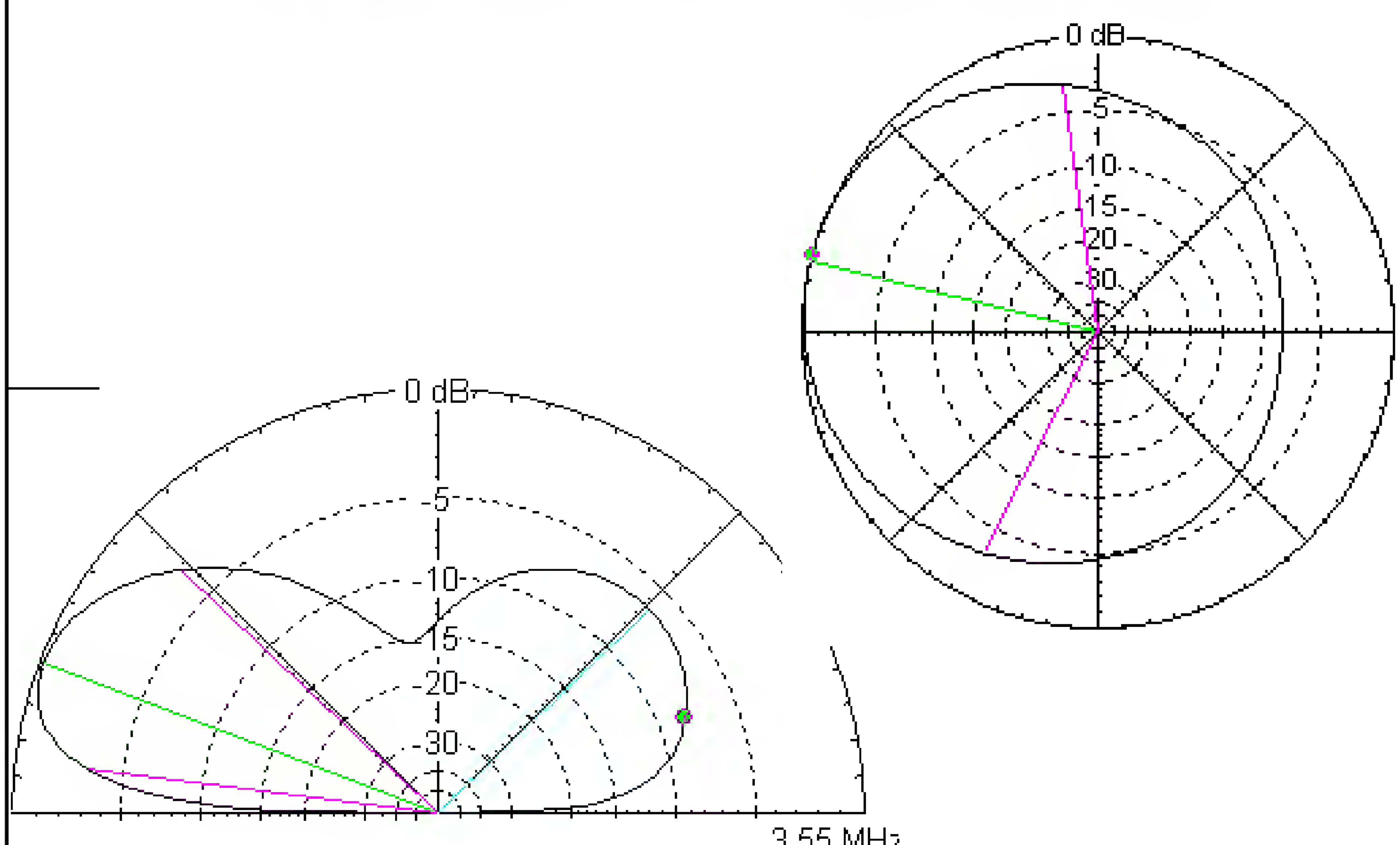
Chokes as “Egg Insulators to Break Up the Feedline



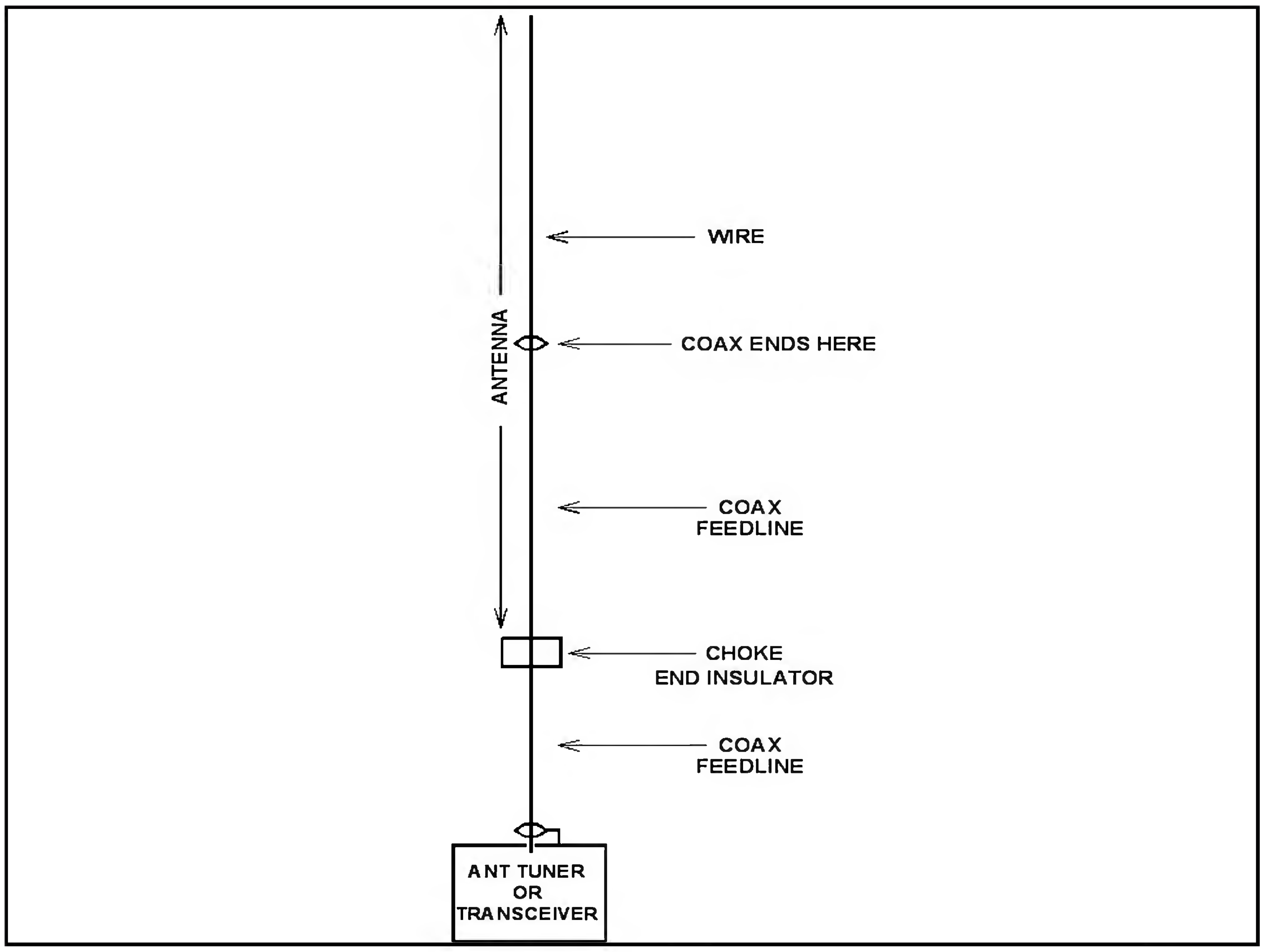
NEC Model of Feedline Interaction with Tee Vertical

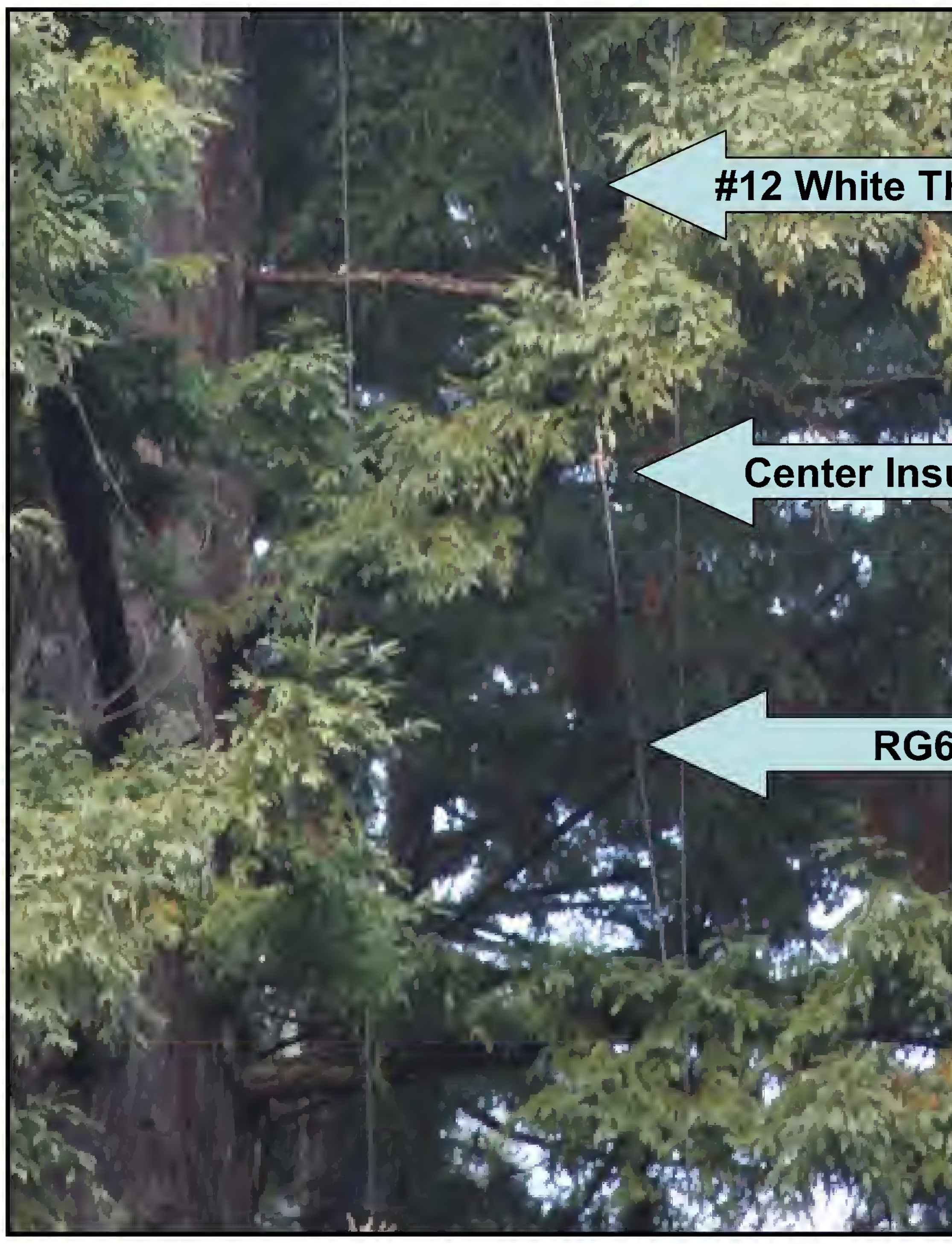


NEC Model of Feedline Interaction with Tee Vertical



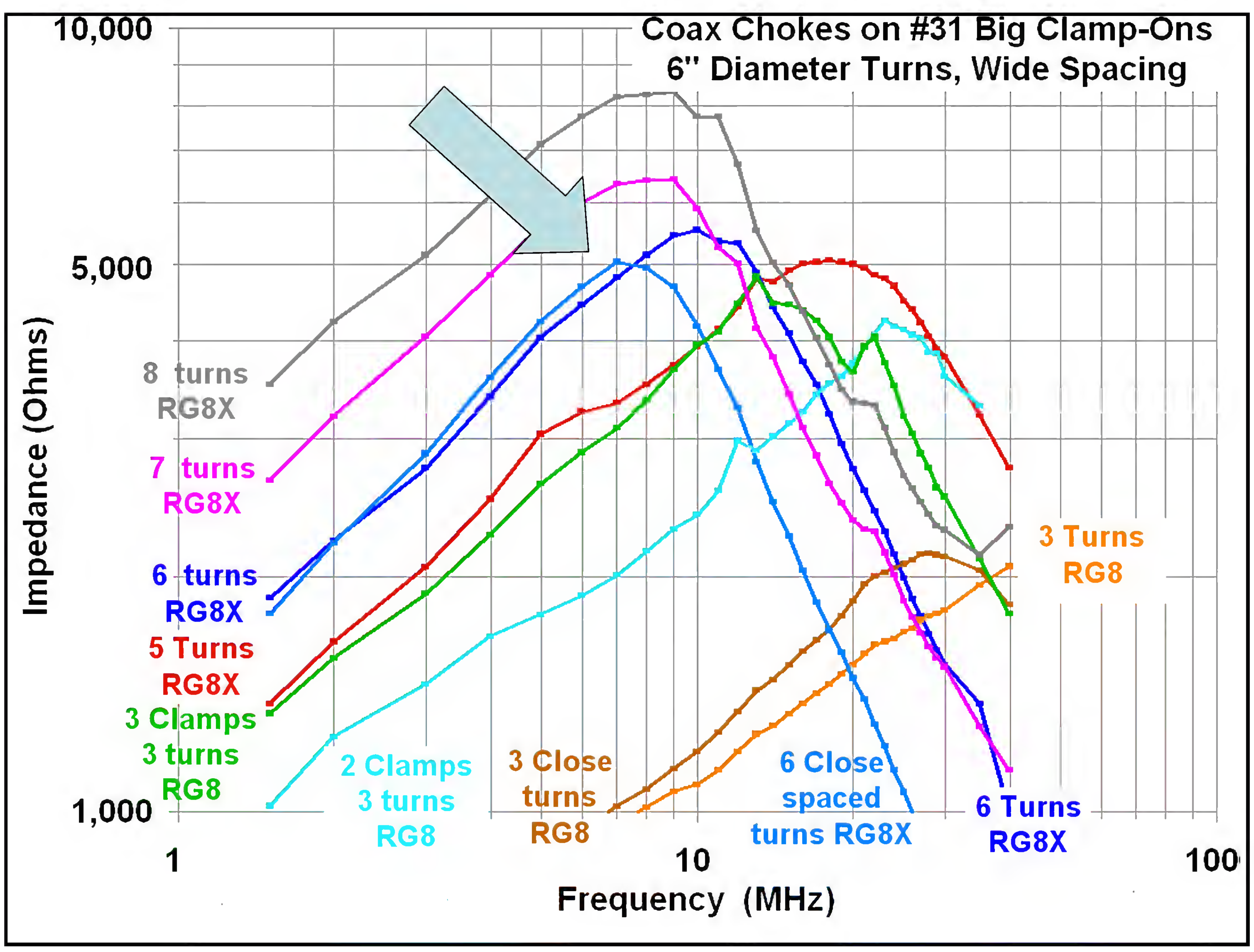
A Choke as the End Insulator of a Vertical Dipole


WIRE
ANTENNA
COAX ENDS HERE
COAX
FEEDLINE
CHOKE
END INSULATOR
COAX
FEEDLINE
ANT TUNER
OR
TRANSCEIVER



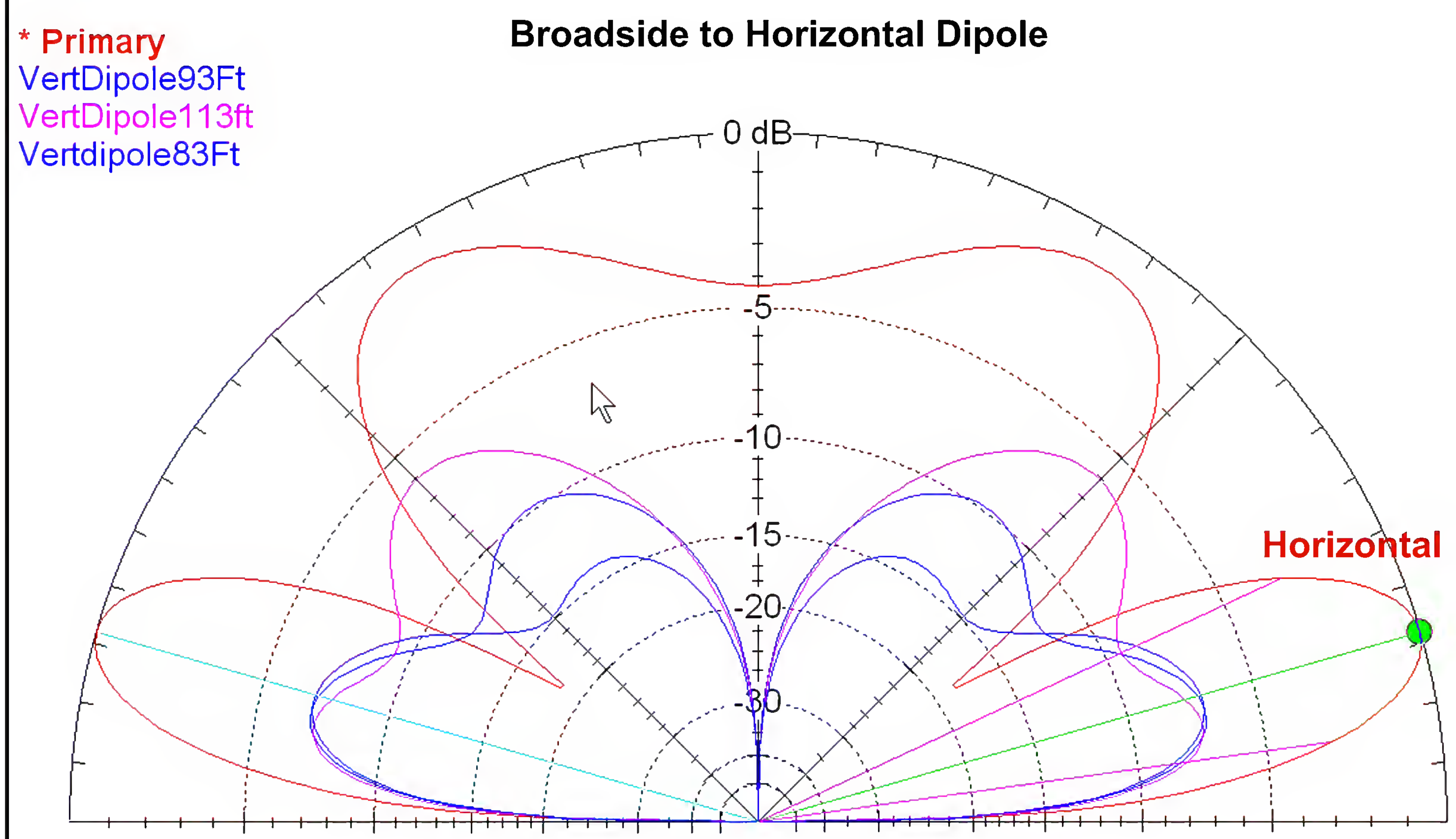
End Insulator for a 40M Dipole

- 6 turns of RG6 around a “big clamp-on” is enough for 500 watts of serious contesting
  - About 5,000Ω resistive impedance
- Two of these 6-turn chokes are needed for 1.5kW
  - About 10,000Ω resistive impedance

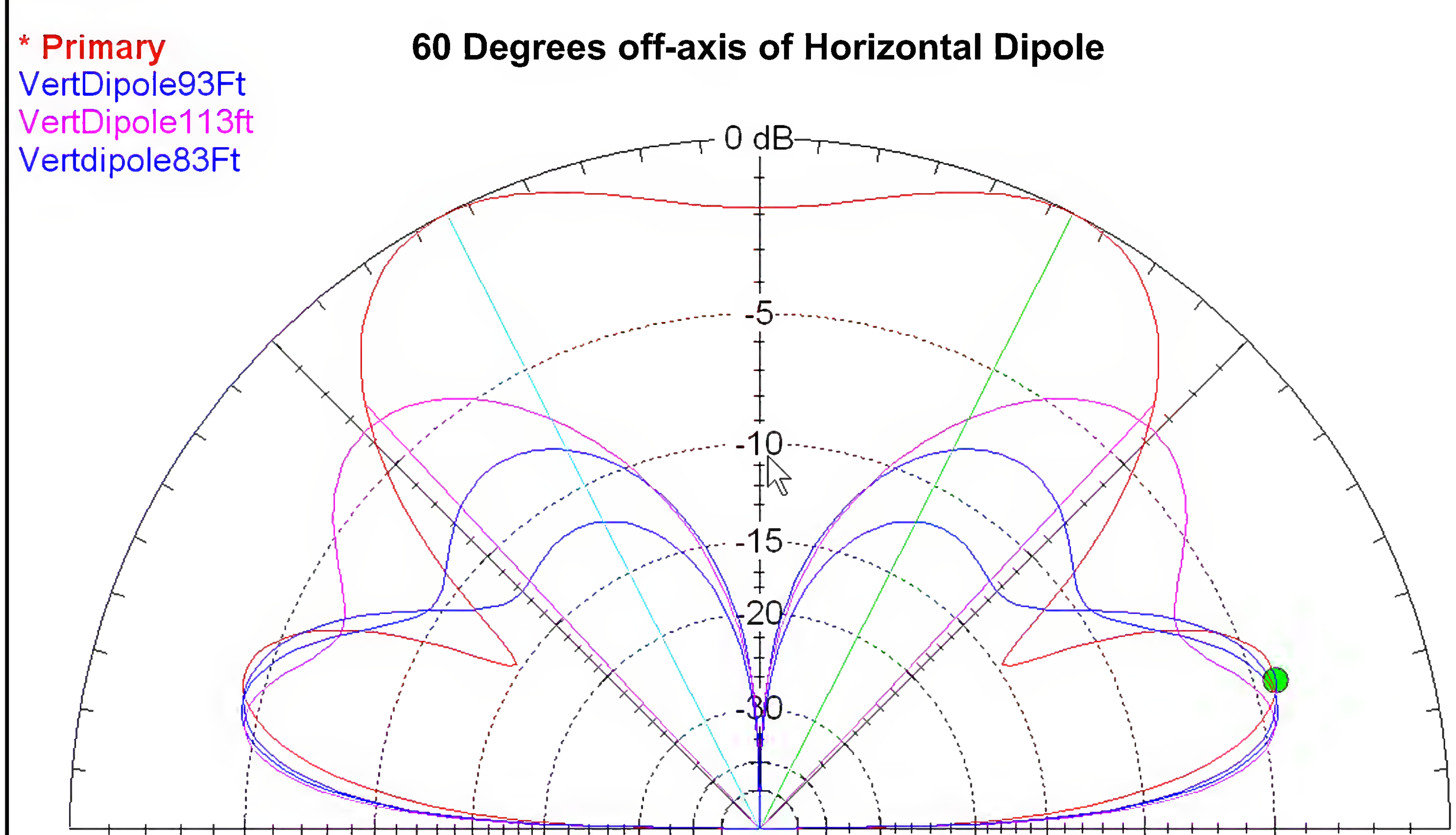


Coax Chokes on #31 Big Clamp-Ons
6" Diameter Turns, Wide Spacing
10,000
5,000
1,000
Impedance (Ohms)
1
10
100
Frequency (MHz)
8 turns RG8X
7 turns RG8X
6 turns RG8X
5 Turns RG8X
3 Clamps 3 turns RG8
2 Clamps 3 turns RG8
3 Close turns RG8
6 Close spaced turns RG8X
6 Turns RG8X
3 Turns RG8

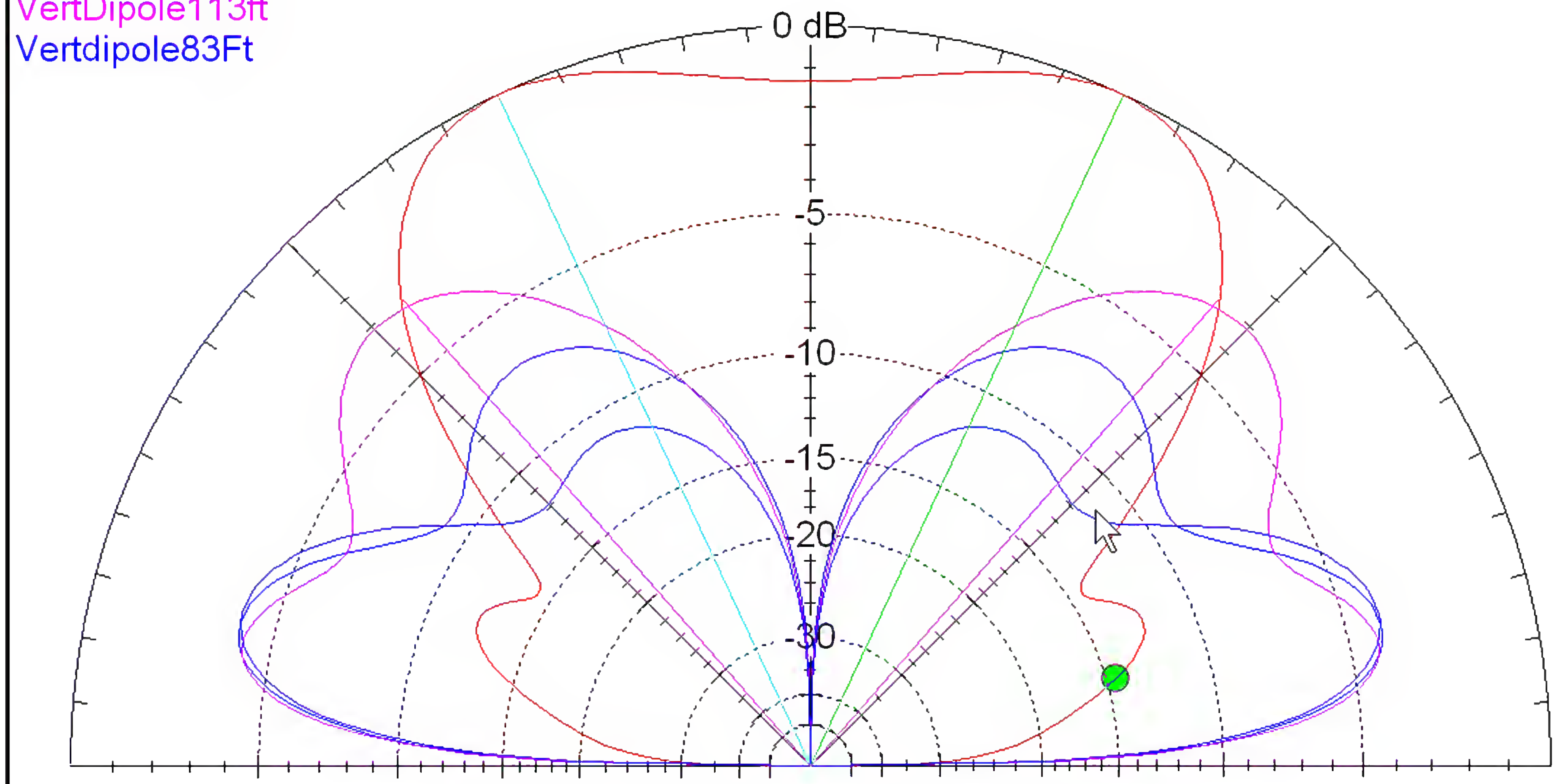
Before you fall in love with a vertical dipole, compare it to a horizontal dipole!



Before you fall in love with a vertical dipole, compare it to a horizontal dipole!

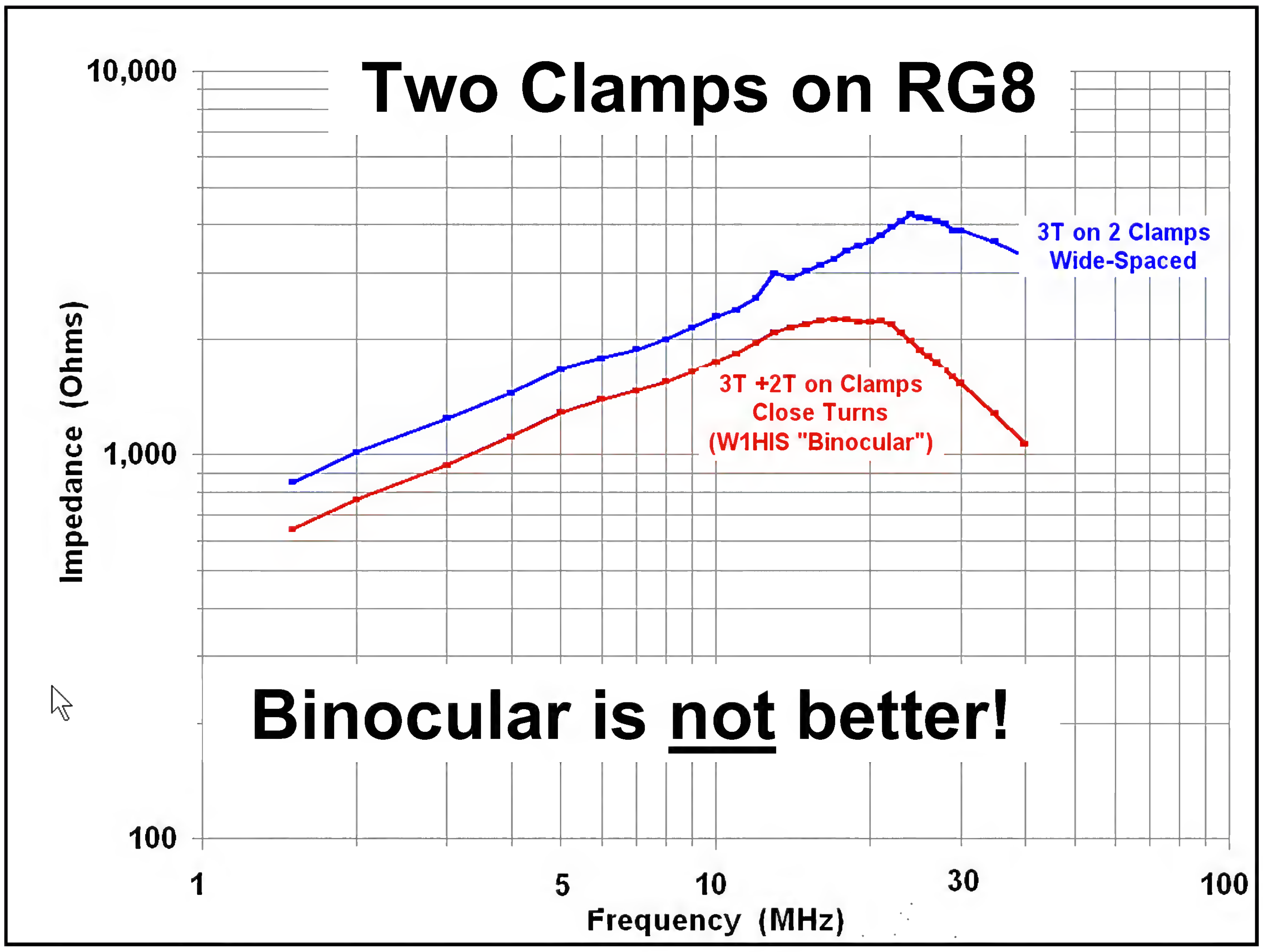


Before you fall in love with a vertical dipole, compare it to a horizontal dipole!



W1HIS Coaxial Choke

#43 cores

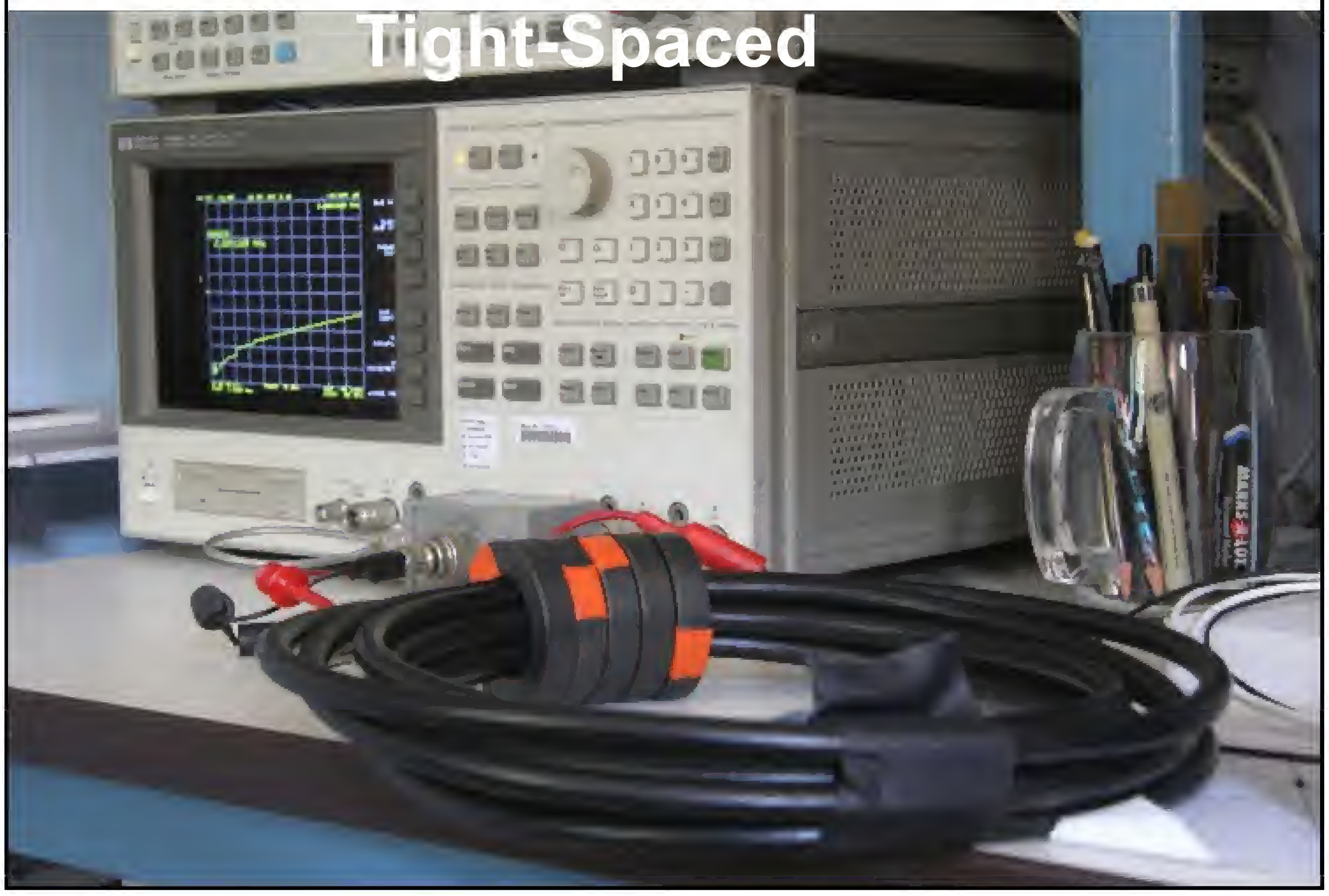


Thanks to Kevin, K6TD

- **Helped me verify my suspicions about reflection-based measurements, and get good S21 data using his HP Network Analyzer**

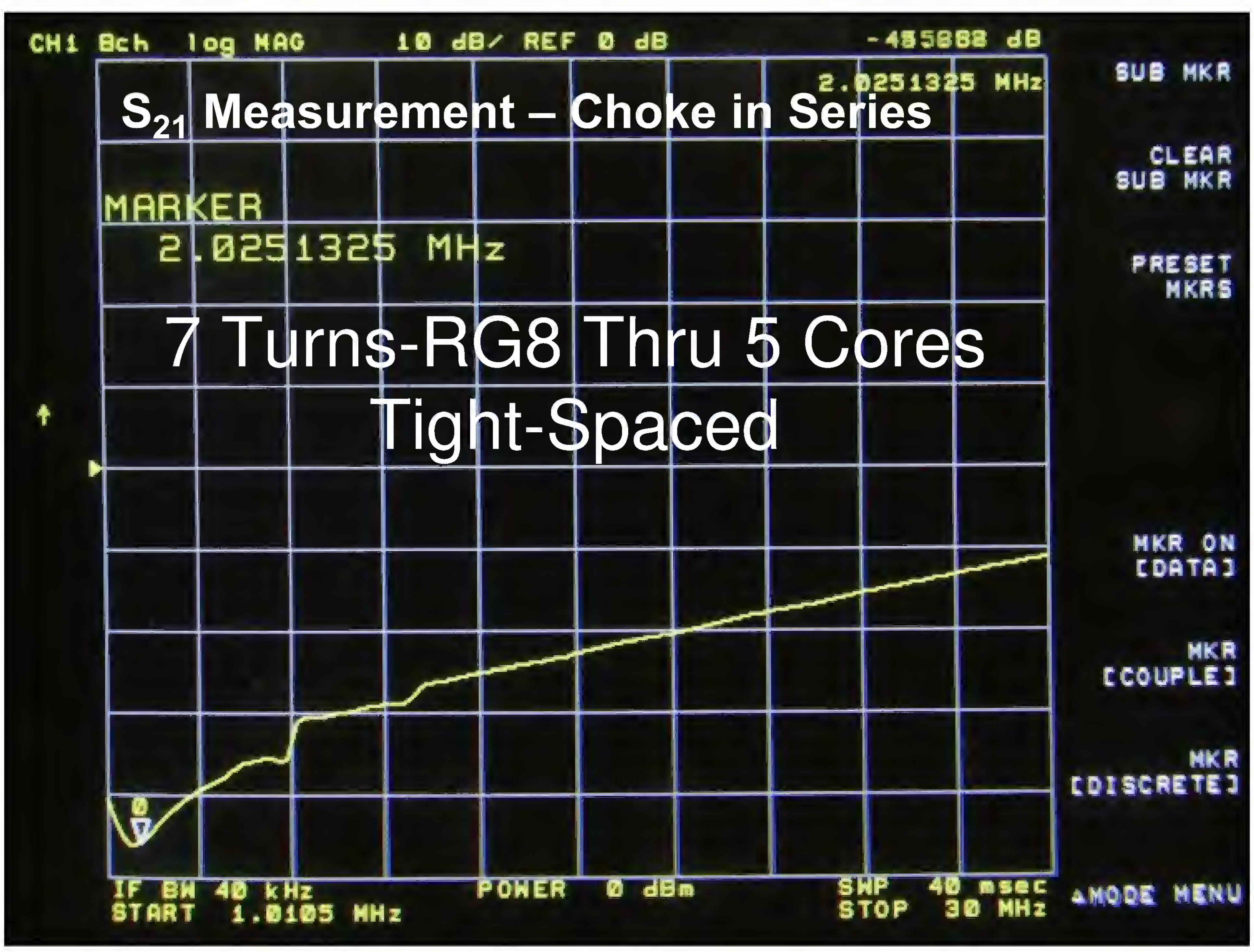
  (Unfortunately, we didn't have the extra hardware to get complex data out of the analyzer into a spreadsheet.)

7 Turns-RG8 Thru 5 Cores
Tight-Spaced

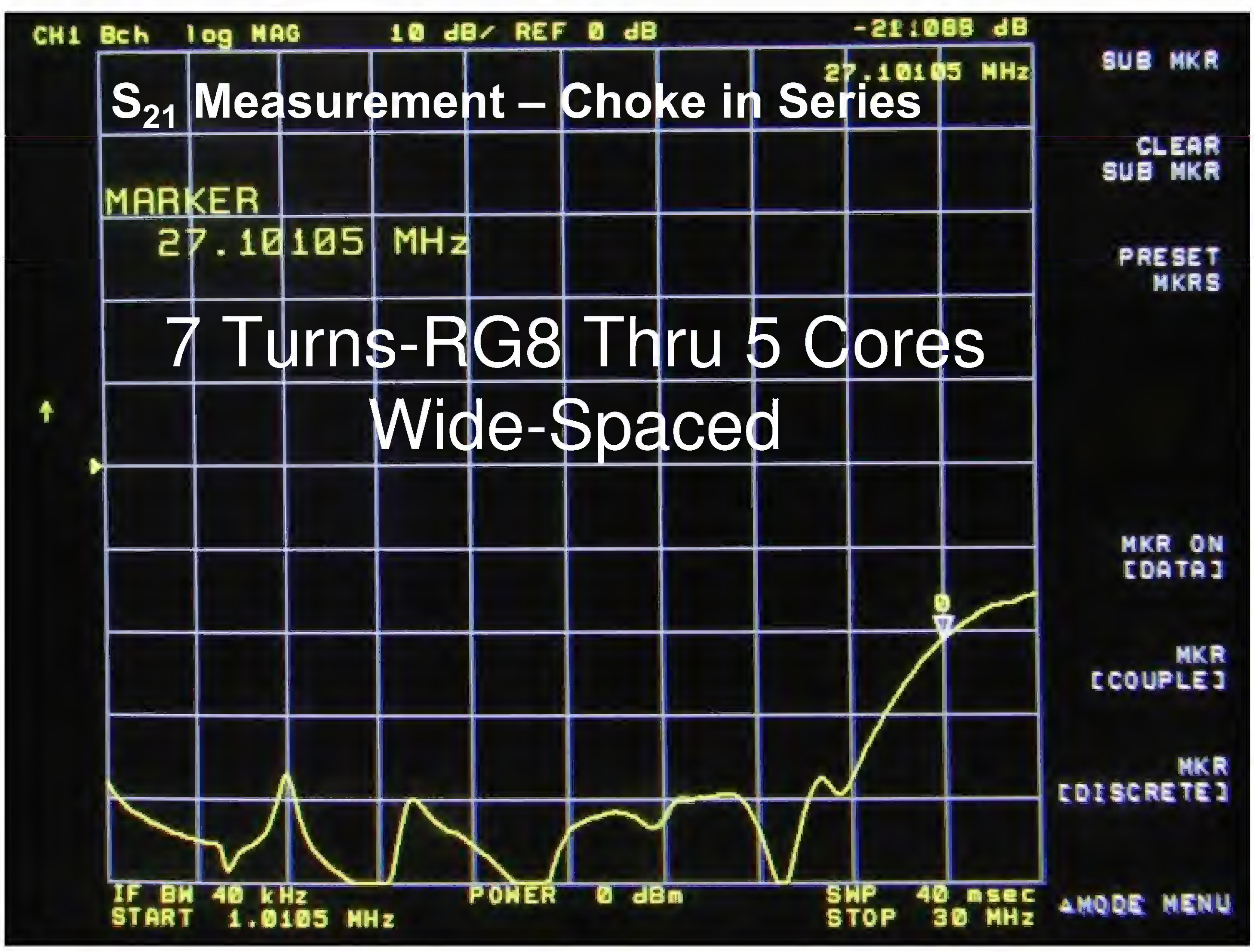


S_{21} Measurement – Choke in Series

7 Turns-RG8 Thru 5 Cores
Tight-Spaced



7 Turns-RG8 Thru 5 Cores Wide-Spaced



Thanks to Chuck, W1HIS

- Chuck was right about using 5,000Ω chokes to minimize receive noise
- Chuck was wrong about how to build 5,000Ω chokes, because he (and his friends) didn't know how to measure them correctly!

More Thanks

- Walt Maxwell, W2DU, for starting it all, his great writing, and for kind words.
- Danny, K6MHE, for prodding me to participate in a measurement roundtable that confirmed my work
- Henry Ott, WA2IRQ, for his insights, criticism, advice, and great teaching.
- Ron Steinberg, K9IKZ, for lots of help at critical times.
- The NCCC crew, for lots of antenna help.

Thanks to Richard Heyser

Dick's "day job" was at JPL, working on underwater communications and communications for the space program, but audio was his hobby.

Dick invented Time Delay Spectrometry (TDS), which revolutionized audio by revolutionizing acoustic measurements. He was an articulate writer and teacher, who taught us how to always think about what we were measuring, to always question the meaning of the data on the screen.

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- **Henry Ott, *Noise Reduction Techniques in Electronic Systems,* Wiley Interscience, 1988**
- **E. C. Snelling, *Soft Ferrites, Properties and Applications,* CRC Press, 1969**
- **E. C. Snelling and A. D. Giles, *Ferrites for Inductors and Transformers,* Research Study Press, 1983**
- ***Fair-Rite Products Catalog*** **This 200-page catalog is a wealth of product data and applications guidance on practical ferrites. http://www.fair-rite.com**
- ***Ferroxcube Catalog and Applications Notes*** **More online from another great manufacturer of ferrites. http://www.ferroxcube.com**

References

- ***New Understandings of the Use of Ferrites in the Prevention and Suppression of RF Interference to Audio Systems* , J. Brown** (AES Preprint 6564)
- ***Understanding How Ferrites Can Prevent and Eliminate RF Interference to Audio Systems*, J. Brown** Self-published tutorial (on my website)
- **A Ham's Guide to RFI, Ferrites, Baluns, and Audio Interfacing** Self-published tutorial (on my website)

Applications notes, tutorials, and my AES papers are on my website for free download
http://audiosystemsgroup.com/publish

Coaxial Transmitting Chokes

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